Fishery Data Series No. 06-64

Klawock Lake Sockeye Salmon (*Oncorhynchus nerka)* Stock Assessment Project 2003 Annual Report and 2001–2003 Final Report

by

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and

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December 2006

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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KLAWOCK LAKE SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) STOCK ASSESSMENT PROJECT: 2003 ANNUAL REPORT AND 2001-2003 FINAL REPORT

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The Division of Sport Fish Fishery Data Series was established in 1987 for the publication of technically oriented results for a single project or group of closely related projects. Since 2004, the Division of Commercial Fisheries has also used the Fishery Data Series. Fishery Data Series reports are intended for fishery and other technical professionals. Fishery Data Series reports are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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ABSTRACT

From 2001 to 2003, our primary study objectives were to estimate the escapement of sockeye salmon (*Oncorhynchus nerka*) into Klawock Lake, and the size of the sockeye harvest in the Klawock Inlet subsistence fishery. The Klawock sockeye run supports the largest subsistence fishery in Southeast Alaska, and in 2001–2003, subsistence fishers consistently harvested about 6,000 sockeye salmon annually. Because the subsistence fishery is open only in July, near the beginning of the sockeye run, a disproportionate number of sockeye salmon are harvested early in the run. For example, in 2003, about 25% of the total run was harvested Klawock Inlet in July, while only about 5% of the run had escaped into the lake by that time. This fishing schedule could result in disproportionate harvest of any sub-populations returning early in the season. Because of high water conditions that can occur in this drainage and compromise weir integrity, we used a mark-recapture estimate instead of the direct weir count in two (2001 and 2003) out of the three years of the study as our official escapement estimate. The sockeye escapement estimate was similar in 2001 (13,200 fish) and 2002 (12,600 fish) and the 2003 estimate was about a third higher (21,300 fish) than the two previous years. Sockeye spawners returning to Klawock Lake showed a higher proportion (33% in 2003) with two years of freshwater growth than in other Prince of Wales Island sockeye populations (typically less than 10%), evidence that limited food resources may slow sockeye fry growth in Klawock Lake. We recommend a systematic analysis of 20 years of limnological information we have already collected, with the ultimate goal of increasing the number of sockeye salmon returning to Klawock Lake.

Key words: sockeye salmon, *Oncorhynchus nerka*, Klawock River, Klawock Lake, Prince of Wales Island, stock assessment, limnology, zooplankton, hatchery, harvest, subsistence, escapement, hydroacoustic

INTRODUCTION

Human population centers commonly develop first in areas with the highest concentration of natural resources. The human occupation of the Klawock Lake area is no exception. The Klawock Lake system, one of the largest sockeye salmon (*Oncorhynchus nerka*) lakes in Southeast Alaska, has been the focus of subsistence fishers since human occupation of this area 7,000 years ago by the Tlingit people. The Klawock River area was one of the most densely settled areas in Southeast Alaska prior to European contact, supported in part by the large number of salmon returning to Klawock River (Langdon 1977). As Europeans began commercial exploitation of the salmon resources in Alaska, the first saltery and cannery in Alaska were built in Klawock Inlet in 1868 (Moser 1898; Roppel 1982). Historical cannery records show that as many as 80,000 sockeye salmon were harvested annually from Klawock Inlet in the early 1900s (Moser 1898). In more recent years, sockeye returns to the inlet have averaged about 20,000 sockeye salmon (sum of subsistence harvest and escapement; Cartwright and Lewis 2004), several times less than the former levels reported in cannery records.

Subsistence and commercial fishers continue to exploit sockeye salmon returning to Klawock River. Household surveys conducted by the Alaska Department of Fish and Game (ADF&G) Subsistence Division in the late 1970s showed that 97% of households in the community of Klawock reported using subsistence fishery resources and 69% specifically reported using sockeye salmon (Paige et al. 1998; Ratner et al. *In press*). From our on-site interviews with subsistence fishers in 2001 and 2002, we estimated about 6,000 sockeye salmon were harvested in this fishery (Lewis and Cartwright 2002; Cartwright and Lewis 2004). Although we were unable to quantify the number of Klawock sockeye salmon harvested in the commercial fishery, 11 years of coded-wire tagging studies indicated that some of the Klawock River sockeye salmon were caught in the District 104 seine fishery (Lewis and Zadina 2001).

Klawock Lake has a long history of stock assessment activity beginning with a weir in the 1930s. The average weir count for eight years in the 1930s was 31,000 sockeye salmon, ranging from 7,000 fish in 1930 to 65,000 fish in 1936 (Lewis and Zadina 2001). We considered these weir counts to be minimum escapement estimates, because of the possibility that fish passed through the weir undetected, the weir was breached by high water, or the weir was not operated throughout the entire sockeye run. No mark-recapture studies were conducted during weir operations in the 1930s to verify the accuracy of the counts. Even so, the 1930s weir counts were, on average, about twice as high as sockeye weir counts in 2001 and 2002, which averaged 16,000 sockeye salmon (Lewis and Cartwright 2002; Cartwright and Lewis 2004).

We have concluded that the weir information from the late 1960s to 1999 is unreliable, after discussions with ADF&G personnel who were present at the Klawock weir during some of these years. During this period the weir was operated inconsistently. Weir records were at times poorly maintained and incomplete. Sometimes the official weir records included mere guesses of daily fish passage, filling in for incomplete records or lost data. During this time, the weir was primarily used to collect broodstock and was operated only during the peak escapement periods (Lewis and Zadina 2001). For example, in some years, the pickets were not in place until August and in other years the pickets were pulled when the hatchery raceway was full. Moderately high water also routinely breached the far end of the weir because there was a gap between the top of the weir and the stream bank. During high water events, the hatchery crew attempted to visually estimate the number of salmon moving past the weir. These estimates were included in records prior to 2001 without any documentation on how these estimates were derived. In 2000, the hatchery crew filled the low area in the weir, replaced the wooden tripods with a permanent aluminum weir frame, and operated the weir for the entire sockeye run. However, a mark-recapture study was not conducted to verify the weir count until 2001. In the first two years (2001 and 2002) we conducted a mark-recapture study to verify the weir counts, the mark-recapture estimate was twice as high as the weir count in the first year (2001), but was within the 95% confidence interval in the second year (2002). Therefore, despite the low weir count in 2001, the mark-recapture estimate of 14,000 sockeye salmon was similar to the weir count and estimate of 13,600 fish in 2002. We attributed the agreement between the weir count and mark-recapture estimate in 2002 to more frequent inspections of the weir for leaks and the fact that no major floods occurred during the sockeye run (Cartwright and Lewis 2004).

The enhancement objectives of the Klawock hatchery also changed over the years. In the late 1970s and early 1980s, the enhancement goal of the hatchery was to increase the number of coho and chum salmon available for harvest by the commercial fleet (ADF&G unpublished documents and memoranda). However, a low escapement count of 900 sockeye salmon in 1983 prompted ADF&G to change its focus to enhancing sockeye salmon production by stocking sockeye fry. In a 1992 ADF&G planning document, the Division of Fisheries Rehabilitation, Enhancement and Development (FRED) hatchery plan team stated that the sockeye enhancement program had not been successful in producing more fish for the District 104 seine fishery or the Klawock Inlet subsistence fishery (Klawock Lake Hatchery Five Year Plan; ADF&G FRED unpublished document by Hansen, Rosenberg, Denton and Haddix 1992). They reiterated the importance of sockeye salmon to these two fisheries and decided that reducing the sockeye harvest through management regulations was not an option. These planners assumed that the reason for the low returns from previous enhancement efforts was due to stocking unfed sockeye fry. Consequently, they developed an elaborate 5-year plan to rear sockeye fry to various stages of development before releasing them into the lake. The focus of this plan was on the survival rate of sockeye fry in the hatchery, not in the lake. The ultimate goal was to annually stock 3.7 million sockeye fry and they expected to produce a total of 175,000 sockeye salmon–with 75,000 fish harvested in the fisheries and 100,000 sockeye salmon returning to the lake as escapement. The plan, however, did not specify marking hatchery fish so that they could be distinguished from wild sockeye salmon. Even allowing for some incomplete weir counts during this hatchery stocking period, the increase of 100,000 fish to the escapement was obviously never realized. Furthermore, the pre-stocking sockeye fry estimate of 900,000 was two to three times higher than any estimate during the enhancement period (Lewis and Zadina 2001; Lewis and Cartwright 2002; Cartwright and Lewis 2004). Hatchery personnel could not quantify the hatchery contribution to the wild Klawock sockeye population until a thermal marking otolith program was initiated in 1999.

Other stressors, associated with urban development, logging, and road-building around the lake, have likely also contributed to the lower production of sockeye salmon in more recent years. We know that the timber harvest and associated road building activity have compromised the function of the spawning streams above Klawock Lake (Klawock Watershed Assessment Phase II, USDA Forest Service, Craig Ranger District, 2001 internal report as part of a contract with the Central Council Tlingit and Haida Tribes of Alaska). For example, in this study, Forest Service biologists conducted a Proper Functioning Condition assessment on 17 reaches in Threemile Creek, the major sockeye-spawning creek in the Klawock watershed. Only one of these 17 reaches was classified as properly functioning: four reaches were non-functional and remaining nine reaches were rated as functional but at risk. These habitat problems most likely have a negative effect on salmon production in the lake, but no studies have been conducted to determine the effects of changes in specific habitat variables on salmon at various stages of their freshwater life history. Unfortunately, because weir counts were incomplete, inaccurate, or unverified in most years, we are not even certain of the size of the sockeye spawning population over time, and therefore cannot draw any conclusions about trends in this population size. Our working hypothesis is that sockeye salmon production has decreased due to human activities at Klawock Lake, but to fully address this hypothesis is beyond the scope of this project.

The primary goals of the research project initiated in 2001 were to 1) accurately estimate the subsistence sockeye harvest by observing and interviewing fishers in Klawock Inlet, and 2) obtain reliable sockeye escapement estimates using a weir and mark-recapture methods. The subsistence harvest component afforded a comparison between the on-site harvest estimates and harvest reported on ADF&G subsistence permits. In estimating escapement, we considered the mark-recapture component especially important due to the history of incomplete sockeye counts at the Klawock weir and frequent failure of the weir due to high water events. We also attempted to independently estimate the sockeye spawning population in each of the major sockeye spawning streams. We estimated the age and sex composition, and average lengths in these classes, for sockeye spawners returning to Klawock Lake in each escapement year. In 2007, we will be able to reconstruct total returns to the sockeye spawning population, by age class, from the 2001 brood year. Additionally, we estimated population sizes and age and length compositions of sockeye smolt and fry populations. We also collected information on the rearing capacity of Klawock Lake including estimates of zooplankton biomass by species and some physical characteristics of the lake, i.e. temperature, light levels, and dissolved oxygen by depth throughout the season. In this report, we present results of the 2003 study and discuss the findings of all three years' study (2001–2003).

OBJECTIVES

1. Estimate the subsistence harvest of sockeye salmon from Klawock Lake, so the estimated coefficient of variation is less than 15%.
2. Count the number of salmon, by species, through the Klawock weir.
3. Estimate the annual sockeye escapement into Klawock Lake with mark-recapture methods, using the weir as a marking platform and the major spawning grounds as the recapture sites, so the estimated coefficient of variation is less than 10%.
4. Estimate the sockeye escapement in the two major spawning streams, Halfmile and Threemile Creeks, using mark-recapture methods on the spawning grounds so the estimated coefficient is less than 15%.
5. Estimate the age composition in the sockeye escapement so that the coefficient of variation is 10% or less for the two major age classes and describe the size composition by age.
6. Describe the age and size composition and timing of the sockeye smolt leaving Klawock Lake.
7. Estimate the sockeye fry rearing density within Klawock Lake, so the estimated coefficient of variation between sample sections is less than 10%.
8. Measure the physical characteristics of the lake and estimate zooplankton species composition and size throughout the season using established ADF&G limnological sampling procedures.

METHODS

STUDY SITE

The Klawock River system (ADF&G stream number 103-60-047) is located on the southwestern side of Prince of Wales Island (lat 55^{o} 32.97'N, long 133^{o} 02.65'W; Figure 1). The lake has a surface area of 11.9 km^2, an elevation of 9.1 m, a mean depth of 17.7 m, a maximum depth of 49 m and a volume of 209 x 10^6 m^3 (Figure 2). This dimictic lake is organically stained with a mean euphotic zone depth (EZD) of 4.2 m, based on the 1986–1988 and 2001–2003 limnological data. Klawock Lake is divided into two distinct basins (Figure 2). Basin A, near the outlet, contains sample stations A and C, and Basin B contains sample stations B and D (Figure 2). Basin A has a maximum depth of 30 m; Basin B has a maximum depth of 49 m and is generally deeper than Basin A. There are four main tributaries to Klawock Lake: Hatchery Creek, Halfmile Creek, and Threemile Creek, which feed into Basin A, and Inlet Creek at the head of the lake, which empties into Basin B (Figure 2). Several small, unnamed tributaries also feed into Basin B on the south side. The drainage areas for Basin A and B are 76.1 km^2 and 37.6 km^2, respectively. The lake empties into Klawock Inlet via the Klawock River (2.85 km). The Prince of Wales Hatchery Association operates an adult salmon weir located approximately 300 m below the lake in Klawock River. Native fish species include cutthroat trout (*Oncorhynchus clarki*), Dolly Varden (*Salvelinus malma*), threespine stickleback (*Gasterosteus aculeatus*), cottids (*Cottus* sp.), steelhead (*O. mykiss*), pink (*O. gorbusha*), chum (*O. keta*), coho (*O. kisutch*), and sockeye salmon. Mysid shrimp (*Neomysis mercedis*) are also present in the lake.

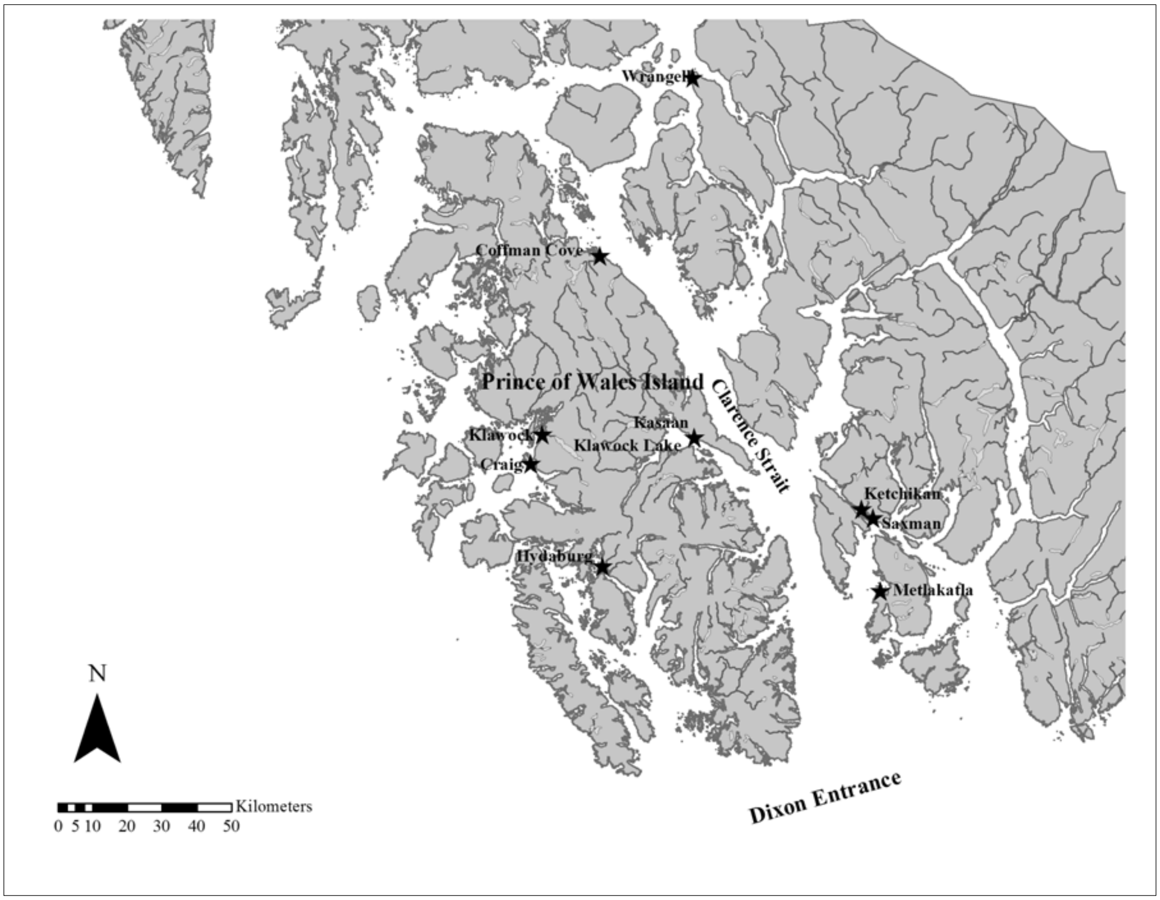


Figure 1.–Map showing location of the village of Klawock and Klawock Lake on Prince of Wales Island, in Southeast Alaska.

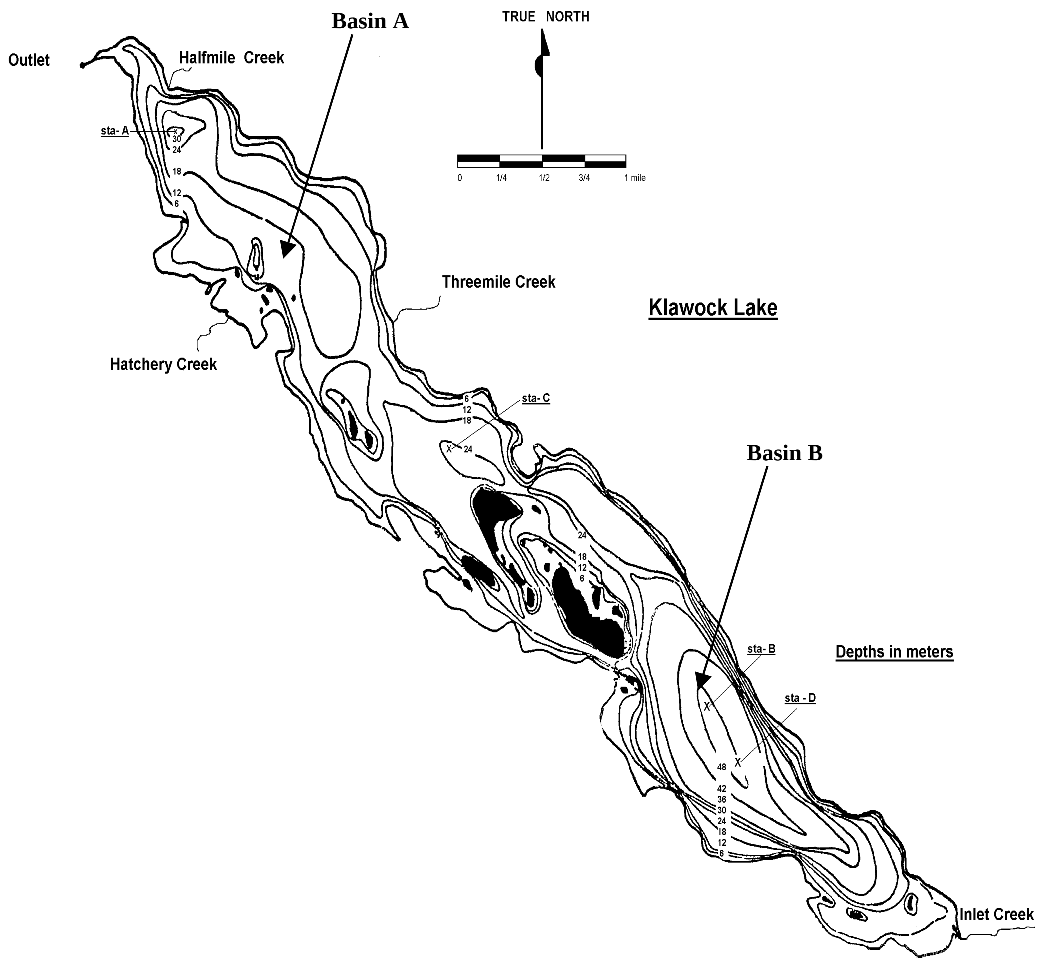


Figure 2.–Bathymetric map of Klawock Lake showing the locations of the limnological sampling stations and inlet streams.

SUBSISTENCE HARVEST ESTIMATE

The subsistence fishery, by regulation, was open from 7 July through 31 July on weekdays starting at 0800 on Monday and ending at 1700 on Friday in all three years. We randomly selected three days out of each five-day week to observe and interview fishers (2003 interview dates listed in Table 1). We divided each sampling day, from 0600 to 2200 hours, into two shifts, 0600–1400 hours and 1400–2200 hours, with reduced hours on Monday and Friday.

Table 1.–Sampling dates selected randomly in each of the four weeks of the Klawock Inlet subsistence fishery in 2003.

Week	Sample Dates
1	7, 9, 11 July
2	14, 16, 18 July
3	21, 23, 24 July
4	28, 29, 31 July

All subsistence fishers used small seine nets, and usually two boats were used to deploy a single net. Therefore, a set was defined as a single net deployment and retrieval, and boat-party referred to a group of people fishing the same net with one or two boats. The samplers used binoculars and a motorized skiff to monitor the boat-parties fishing and positioned themselves on the shore or in the boat so that they could see all the boat-parties fishing in Klawock Inlet. As a net was being pulled up, the interviewer approached the participants to verbally interview them or the interviewer observed the set and recorded the pertinent information. In addition to the verbal interviews and visual observations, samplers and fishers also developed a series of hand signals to communicate the size of the catch. If the technician received information from hand signals, he did not verbally interview the participants; hand signals were most often used to indicate zero fish in a set. Verbal interviews were more commonly used when larger numbers of fish were caught in a set. The crew recorded the date and time of interview, the place of residence of the fishers, the amount of time the gear was set, the number and species of fish caught, and whether the information was collected verbally, visually, or by hand signals. The sampler assigned a number to each interview. Names of fishers were not recorded to guard the confidentiality of the fishers. Samplers made every effort to interview all participants after each set. If a boat-party left the area before participants could be interviewed, the sampler recorded a missed interview for that set.

Data Analysis

We viewed the statistical population to be a collection of “net sets.” Sets were organized into a day within a week. The sampling was constructed as a two-stage sampling plan, with a day within a week selected at random (first stage) and then a set within a day (second stage) selected if need be (Bernard et al. 1998; Thompson 1992). If a set was recorded as a “missed interview,” the average harvest for that day was assigned to that set (second stage). The average harvest per day, within a week, was expanded to estimate the harvest for the two days not sampled each week (first stage). If harvest data were collected for all sets on the days sampled within a week (i.e. no missed interviews), that week’s estimate only required expansion of the average daily harvests to the full week (five fishing days).

We let h_{ijk} denote the harvest for set i on day j in week k, and m_{jk} denote the number of completed interviews on day j, in week k (i.e. the total number of sets for which interviews were obtained). Also, M_{jk} denoted the total number of net sets counted on day j in week k (i.e. the total number of sets observed, including any missed interviews), and d_k denoted the total number of days sampled out of D_k fishing days in week k. For all weeks, d_k was 3. For the first three weeks of the fishery, D_k was 5, and for the fourth week, D_4 was 4. For a given species, the harvest for week k was estimated as,

$$\hat{H}_k = \frac{D_k}{d_k}\sum_{j=1}^{d_k}\frac{M_{jk}}{m_{jk}}\sum_{i=1}^{m_{jk}}h_{ijk} \ ,$$

and the total harvest for the season was estimated as the sum of weekly harvests,

$$\hat{H} = \sum_{k=1}^{4}\hat{H}_k \ .$$

To estimate the variance of $\hat{H}$, we let $\bar{h}_{jk}$ denote the mean harvest per set, on day *j* in week *k*, and $\bar{h}_k$ denote the mean harvest for the week. We then estimated the variance for the estimated harvest in week *k* as,

$$\text{var}(\hat{H}_k) = \frac{D_k}{d_k}\sum_{j=1}^{d_k} M_{jk}^{\,2}\left(1 - \frac{m_{jk}}{M_{jk}}\right)\frac{\sum_{i=1}^{m_{jk}}(h_{ijk} - \bar{h}_{jk})^2}{m_{jk}(m_{jk} - 1)} + D_k^{\,2}(1 - \frac{d_k}{D_k})\frac{\sum_{j=1}^{d_k}(\bar{h}_{jk} - \bar{h}_k)^2}{d_k(d_k - 1)}$$

(Thompson 1992, p. 129).

The overall variance for the season was estimated by summing the four weekly variance estimates, $\text{var}(\hat{H}) = \sum_{k=1}^{4}\text{var}(\hat{H}_k)$. Finally, this overall variance was used to calculate the standard error of the estimate.

SOCKEYE ESCAPEMENT ESTIMATES

Weir Counts

The hatchery operated an aluminum-framed picket weir from 24 June 2003 to 7 January 2004 on Klawock River. The weir is located about 300 ft below the lake, adjacent to the Prince of Wales Hatchery, and is about 50 m in width. The sockeye stock assessment project crew, in cooperation with the hatchery crew, counted all salmonids, by species, that entered the lake between 24 June and 25 October 2003. Hatchery personnel passed and counted the few remaining salmon to enter the system after 25 October. The hatchery and project crews counted all salmon through the weir via the hatchery raceway. The fish enter the hatchery holding ponds at the top of the raceway and are then crowded to the far end of the pond and either mechanically or hand brailed onto a sampling platform. All fish except sockeye and coho salmon were immediately released back into the river above the weir. Sockeye salmon to be sampled were placed in a holding area or immediately sampled and then released upstream of the weir. Coho salmon were sorted into a second tank for broodstock and cost recovery or released as escapement above the weir. For both sockeye and coho salmon, jacks were counted separately from fully-grown adult fish. The crew also measured water depth, air temperature, and river surface temperature daily, and recorded the number of unmarked and marked sockeye mortalities recovered from the face of the weir.

Weir Mark-Recapture Estimate

To test the integrity of the weir and provide an independent estimate of sockeye escapement into Klawock Lake, we also estimated escapement using a closed, stratified mark-recapture model. The weir mark-recapture study was considered especially important in Klawock Lake due to the size of the river and the high water events that often breached the weir structure in former years (Lewis and Zadina 2001; Lewis and Cartwright 2002; Cartwright and Lewis 2004). If the 95% confidence interval of the mark-recapture estimate did not contain the weir count, and the mark-recapture estimate was judged not to be highly biased, the mark-recapture estimate was used as the official escapement estimate. The number of sockeye salmon taken for broodstock in the lake was subtracted from this official escapement estimate.

The crew marked 21% of the fish that passed through the weir daily with a primary mark (adipose fin clip) and a secondary mark (opercular punch) denoting the time period in which the fish was marked. Marked fish were handled quickly to minimize stress and were released above the weir. By means of the secondary marks, marking was stratified into four time periods: 1) single left round punch for 20 June–31 July; 2) double left round punch for 1–31 August; 3) single left triangle punch for 1–30 September, and 4) double left triangle punch for 1–25 October. A stratified estimate could be less biased in the event that initial capture rates varied greatly over time, for example, if the weir failed during a flood or marking rates dropped below 20% for an extended period (Arnason et al. 1996).

Beginning 1 August, the crew sampled fish weekly on the spawning grounds in Halfmile, Threemile, Hatchery, and Inlet Creeks for the recapture portion of the weir mark-recapture study. Live and dead fish were counted and examined for marks. Each fish captured and examined was given a third mark (right opercular punch) to prevent duplicate sampling in a later sampling period. Prior to conducting the recapture sampling each week, the crew visually estimated sockeye spawners in each stream. Each observer counted fish separately, and then their counts were averaged.

Data Analysis

The two-sample Petersen method is a simplistic model for estimating total escapement based on the total number of fish marked at the weir (first sample), the total number of fish subsequently sampled for marks on the spawning grounds (second sample), and the number of marks recovered in the second sample (Seber 1982, p. 59; Pollock et al. 1990). Stratified mark-recapture models extend the two-sample Petersen method over two or more sampling occasions or events in both the marking (first) and mark-recovery (second) samples. Stratified models are also widely used for estimating escapement of salmonids as they migrate into their spawning systems (Arnason et al. 1996). Spawning migrations may last for a month or more, during which there can be substantial variation in biological parameters such as daily immigration or mortality rates. A fundamental assumption of the Petersen and related mark-recapture models is that capture probabilities for individual animals are equal (Pollock et al. 1990). The natural variation typical of salmon escapements presents many possibilities for individual capture probabilities to vary, but if certain conditions are met, assumptions of equal capture probability can be used to simplify the model. Briefly stated, the three assumptions of equal probability of capture required by the Petersen model are: 1) all fish have an equal probability of capture in the first sample (marking), 2) all fish have an equal probability of capture in the second sample (mark-recovery), and 3) fish mix completely between the first and second sample. Generally, if one or more of these assumptions is met, data from all marking and all mark-recovery samples can be pooled with little or no bias, thereby providing the most precise estimate. However, if none of the assumptions are met, the pooled Petersen estimate can be badly biased (Arnason et al. 1996).

We used the Stratified Population Analysis System (SPAS) software as an aid in analyzing and interpreting our mark-recapture results (Arnason et al. 1996; for details, refer to http://www.cs.umanitoba.ca/~popan/). SPAS calculates Darroch and "pooled Petersen" estimates, and provides two goodness-of-fit tests to compare observed and expected capture probabilities in the marking (first) and mark-recovery (second) samples (Arnason et al. 1996). This program also provides associated standard errors of the estimates. The test of the assumption of complete mixing is incorporated into the test for equal probability of capture in the second sample. We considered a test statistic with p-value ≤ 0.05 as "significant."

We looked at sample sizes and capture probabilities in each marking and mark-recovery stratum, and considered any natural events such as flooding or failures of our technicians to follow the sampling design. We then checked the Darroch estimate for possible problems, such as a failure of the SPAS program to find a solution, or estimates much larger or smaller than the pooled

Petersen estimate. Followed the guidelines and suggestions in Arnason et al. (1996) we searched for a pooling scheme that led to the fewest number of strata with non-significant test statistics and an absence of other diagnostic problems.

Stream Mark-Recapture Estimates and Visual Surveys

In addition to the weir mark-recapture estimate for the whole lake, we also estimated the number of sockeye salmon spawning in Halfmile and Threemile Creeks to provide stream specific estimates of the sockeye spawning population in 2003. These estimates of stream spawning populations were compared to the weir mark-recapture estimate to determine if we could approximate the whole lake escapement estimate by estimating spawning populations in the major inlet streams, without using the weir. We focused our efforts on Halfmile and Threemile Creeks because they accounted for about 73% of the sockeye spawners counted in all four major tributaries in Klawock Lake in 2001 and 2002 (Lewis and Cartwright 2002; Cartwright and Lewis 2004).

The field crew conducted four mark-recapture sampling trips in Halfmile Creek between 9 September and 15 October and three trips in Threemile Creek between 9 September and 8 October. The crew attempted to sample each stream at least once a week due to the short residence time of sockeye spawners in these streams (Lewis and Cartwright 2002, Cartwright and Lewis 2004). Each stream was defined as a separate sampling domain. Prior to each mark-recapture event, the crew conducted visual surveys to count sockeye spawners in Threemile and Halfmile Creeks, and also in Inlet and Hatchery Creeks, the two other sockeye spawning tributaries in the Klawock Lake watershed.

In each stream, sockeye salmon were captured as they schooled at the mouth of the stream before going upstream to spawn, using a beach seine 20 m long by four m deep, deployed by a small, motorized skiff. All captured sockeye salmon were first inspected for previous marks, and if marked, were released without counting or applying additional marks. All unmarked fish were counted, marked, and released, with the mark indicating the sampling event: 9 September (event 1)–single left square opercular punch; 15 September (event 2)–double left square punch; 30 September (event 3)–adipose fin clip; 7–8 October (event 4, at Halfmile Creek only)–caudal fin clip.

As soon as sockeye salmon were observed spawning in the streams, the recapture phase began. Crew members used dip nets to capture salmon, sampling as evenly as possible in all parts of the stream. The total sample size, the number of new fish marked, and the number of recaptured fish with each type of mark were recorded. Right opercular punches were used to identify fish that had already been sampled, to prevent re-sampling. Recapture events took place on 16 September, 1 October, 8 October, and 15 October (Halfmile Creek only).

Data Analysis

Similar to the weir mark-recapture study, we attempted to estimate the stream-spawning populations using the Darroch and pooled Petersen methods included in the Stratified Population Analysis System (SPAS) software (Arnason et al. 1996). As in the weir mark-recapture analysis, we looked at sample sizes and capture probabilities in each marking and mark-recovery stratum, and considered any natural events such as flooding or failures of our technicians to follow the sampling design. We then checked the Darroch estimate for possible problems, such as a failure of the SPAS program to find a solution, or estimates much larger or smaller than the pooled Petersen estimate. Followed the guidelines and suggestions in Arnason et al. (1996) we searched for a pooling scheme that led to the fewest number of strata with non-significant test statistics and an absence of other diagnostic problems.

SOCKEYE ADULT AGE AND LENGTH COMPOSITION

In 2003, as in the previous two years, we collected over 600 length, sex and scale samples from adult sockeye salmon to describe the size and age structure of the population, by sex. The length of each fish was measured from mid eye to tail fork and to the nearest millimeter (mm). The sex of the fish was determined by the length and shape of the kype or jaw. The crew took three scales from the preferred area of each fish (INPFC 1963), and prepared them for analysis as described by Clutter and Whitesel (1956). Scale samples were analyzed at the ADF&G salmon aging laboratory in Douglas, Alaska. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3 denotes a five-year-old fish with one freshwater and three ocean years). The weekly proportion in each age class, and the mean weekly proportion in each age-sex group, weighted by total escapement per week, were estimated. Associated standard error was estimated using standard statistical techniques and assuming a binominal distribution (e.g. Thompson 1992). We expect that this binomial assumption would adequately approximate the standard error, even though we used a systematic sample rather than a random sample. Mean lengths by age and sex were likewise estimated from weekly means, weighted by the total escapement per week.

SOCKEYE SMOLT AGE, LENGTH, AND WEIGHT COMPOSITION

To determine the age and size characteristics of the sockeye smolt population and to describe the run timing, we collected sockeye smolt emigrating from Klawock Lake from 30 April to 4 June in 2003. During the early part of the emigration when the water was low, a fyke net with a two m x two m opening and a three mm mesh nylon cover was attached to the adult salmon weir frame approximately 50 feet from the west bank of the river. On 24 May the water level was high enough to collect the smolt in an eight-foot diameter screw trap that we suspended from the weir frame in the same place as the fyke net. We tallied the number of smolt present daily by transferring the smolt into a white 5-gallon bucket and counting them as we slowly poured the smolt back into the river. Twenty smolt were sub-sampled daily for biological characteristics and frozen. If less than twenty fish were caught in a day, all smolt were sampled. We weighed each smolt to the nearest 0.1 g and measured their snout to fork length to the nearest mm. Scales were collected and mounted on microscope slides, and aged using a Carton microscope with a video monitor and interpreted scale growth patterns with the methods of Mosher (1968). Two trained technicians independently aged each smolt scale, and the two sets of ages were compared. Cases with a discrepancy in age determination were omitted from the set of samples used for analysis. Although we did not estimate the smolt population, we determined the proportion of age-1 and age-2 smolt in the population by weighting the proportion of each age class in the biological samples by the number of smolt counted in the trap (Sokal and Rohlf 1987). Weighting the proportion of each smolt age class with the number of smolt leaving the lake each day was not done in 2001 and 2002.

SOCKEYE FRY POPULATION ESTIMATE

We used hydroacoustic and mid-water trawl sampling methods to describe the distribution of small pelagic fish and to estimate the abundance of sockeye salmon fry in Klawock Lake in 2003, as in the two previous years. In 2002, we also conducted a survey in October to compare estimates and document the movement of fry from Basin A to Basin B prior to the winter

(Cartwright and Lewis 2004). To control year-to-year variation in our estimates, we conducted the 2003 acoustic survey using the same fourteen transects (two transects in each of the seven sample sections) that were randomly chosen in 2002.

Hydroacoustic Survey

During the acquisition of acoustic targets, we surveyed each selected transect from shore to shore, beginning and ending the sampling at the depth of 10 m. Sampling was conducted during the darkest part of the night. A constant boat speed of about 2.0 m · sec^{-1} was attempted for all transects. The acoustic equipment was the Biosonics DT-4000™ scientific echosounder (420 kHz, 6° single beam transducer), and version 4.0.2 of the Biosonics Visual Acquisition© software was used to collect and record the data. The ping rate was set at five pings · sec^{-1} and the pulse width at 0.4 ms. Only target strengths ranging from –40 dB to –68 dB were recorded because this range represented fish within the size range of juvenile sockeye salmon and other small pelagic fish.

Trawl Sampling

We conducted midwater trawl sampling in conjunction with hydroacoustic surveys to determine species composition of pelagic fish and age distribution of sockeye fry. A two m x two m elongated beam-trawl net with a cod-end was used for trawl sampling. Trawl sampling was conducted in the area of the lake with the highest concentration of fish, identified during the hydroacoustic survey. We performed one tow at the surface, two tows at 10 m, and two tows at 12 m in each basin (A and B). The duration of each trawl was 20 minutes.

All adult fish caught in the midwater trawl were identified, counted, and released. All small fish from the trawl net were euthanized with MS 222 and preserved with 90% alcohol. Samples from each tow were preserved in separate bottles, labeled with the date, lake name, tow number, tow depth, time of tow, and initials of collectors.

In the laboratory, fish were re-hydrated by soaking in water for 60 minutes prior to measurement. All fish were identified to species, and snout to fork length (to the nearest millimeter) and weight (to the nearest 0.1 gram) were measured. All sockeye fry under 50 mm were assumed to be age-0. Scales were collected from sockeye fry over 50 mm and mounted onto a microscope slide for age determination. Scales were examined through a Carton microscope with a video monitor and aged using methods outlined in Mosher (1968). Two trained technicians independently determined age for each sample. Results of each independent age determination were compared. In instances of discrepancy between the two age determinations, a third independent examination was conducted.

Hydroacoustic target estimates were allocated by species according to the proportions of each species caught in the trawl samples, and sockeye fry were further allocated into age classes. The process of capturing juvenile fish with a trawl was characterized using a hierarchical Bayesian model, assuming a separate random rate for each category of sonar target in each trawl pass. Rates of sockeye acquisition for each specific trawl pass were assumed to follow a beta sampling distribution, with a common set of parameters for the whole lake.

Data Analysis

We used Biosonics Visual Analyzer © version 4.0.2 software to analyze the sonar record. Echo integration was used to generate an estimate of target density (targets · m^{-2}) for each sample transect (MacLennan and Simmonds 1992). In 2003, as in 2002, we divided Klawock Lake into seven sampling sections, with two transects per section. Mean target density for each section was estimated using the two replicate target density estimates. We calculated a sample variance for each section estimate with one degree of freedom. The mean target density for the whole lake was estimated as the average of the target-density estimates for each section, weighted by surface area of each section. Total targets in the lake were estimated by summing the target population estimates for each section. Because we sampled each section independently from other sections, the estimated sampling variance for the whole-lake target population estimate was simply the sum of variances for each section. We reported sampling error as a coefficient of variation (Sokal and Rohlf 1987).

The estimate of total targets was partitioned into two categories, sockeye fry and other small fish, by means of the trawl samples. Commonly, researchers assume that the proportion of sockeye fry in such a sample follows a binomial distribution, but this is often an assumption of convenience and not necessarily a realistic representation of the sampling conditions. We know from previous experience with many sockeye-producing lakes that the number of sockeye fry in a trawl sample is often much more variable than the binomial sampling model predicts. Thus, in practice, the confidence intervals based on binomial sampling assumptions can be biased and far too short.

We developed the following Bayesian procedure to measure uncertainty in the estimated proportion of sockeye fry. Let T denote the actual value of the total targets in the lake, and let $\hat{T}$ denote the estimate of T, derived from the echo integration analysis of the sonar record. Conditioned on total number of fish caught in the i^{th} trawl sample, we let number of sockeye fry in each trawl follow a binomial sampling distribution. For the i^{th} trawl pass, we denote trawl sample size as n_i and we denote number of sockeye fry in this sample as y_i. We let parameter p_i denote the unknown underlying proportion of sockeye fry in the i^{th} trawl sample, and we assume p_i is a key parameter in the sampling distribution of y_i. We assume each trawl sample has its own sampling distribution, possibly different from any other in the lake. Next, we suppose that p_i is itself drawn from a beta probability distribution with mean $p_\mu = \dfrac{\alpha}{\alpha + \beta}$.

In other words, let y_i be distributed as a binominal random variable with parameters p_i and n_i, and let p_i follow a beta probability distribution with parameters α and β. Again, α and β are the same for each transect in the lake at the occasion of trawl sampling. The hyperparameters α and β can be estimated through all of the trawl hauls.

We chose a uniform distribution between 0 and 10 for both α and β hyperparameters after experimenting with this distribution and truncated normal distributions. This prior distribution limits influence of prior distributions on posterior distributions and ensures that the data have adequate influence if sample size is large. For example, for sample sizes less than 10, the posterior distribution will be almost entirely controlled by prior distribution. However, for sample sizes approaching 100, the prior distribution will have little influence on mean of the posterior distribution for each individual p_i. We note that if posterior probability is allowed to build up on larger and larger values of α and β, the posterior means of the p_i's will become more alike and the posterior variance of p_μ will decline unrealistically. Therefore, limiting maximum values of both α and β to 10 seemed to provide a compromise between allowing posterior means of individual p_i's to be either alike or unalike, and still allow data (likelihood) to dominate posterior distribution.

Let S denote the number of targets assigned to sockeye fry. To compare and combine an estimate of S and T in the same context as the Bayesian estimate of p_μ, we assumed the posterior distribution of T would be approximately normally distributed. We then generated at least 5,000 random draws from a normal distribution with the same mean and variance as the sample mean and sample variance for T. We previously generated 5,000 observations of posterior distribution of p_μ. Denoting each random draw with subscript j, we calculated a random draw from posterior distribution of S as $S_j = p_j T_j$. From there we noted the mean of the 5,000 simulated values of S and we generated 95% credible intervals—the Bayesian counterpart to a 95% confidence interval—using 2.5 and 97.5 percentiles of simulated posterior distributions of S. All analyses were performed with Winbugs software.

LIMNOLOGY SAMPLING

Limnology sampling was conducted at four stations (Stations A and C in Basin A and Stations B and D in Basin B) on six sampling dates between April and October 2003. We measured underwater light intensity, dissolved oxygen, and temperature by depth, and collected zooplankton samples. We measured light, temperature and dissolved oxygen profiles only at the primary sample sites, Station A in Basin A and Station B in Basin B. We collected zooplankton samples at all four stations on each sampling date.

Light, Temperature, and Dissolved Oxygen Profiles

We recorded underwater light intensity from just below the surface to the depth where measured intensity was one percent of the surface light reading, at 0.5 m intervals, using an electronic light sensor and meter (Protomatic). The natural log (ln) of the ratio of light intensity just below the surface to light intensity at depth z (I_0/I_z) was calculated for each depth. The vertical light extinction coefficient (K_d) was estimated as the slope of ln(I_0/I_z) versus depth. The euphotic zone depth (EZD) was defined as that depth at which light has attenuated to one percent of the intensity just below the lake surface (photosynthetically available radiation, 400–700nm) (Schindler 1971), and was calculated using the equation, EZD = 4.6205/ K_d (Kirk 1994).

We measured temperature and dissolved oxygen (DO) throughout the water column with a Yellow Springs Instruments (YSI) Model 58 DO meter and probe, in relative (percent of saturation) and absolute (mg L^{-1}) values for DO and in ºC for temperature. Measurements were made at 1-m intervals to the first 10 m or the lower boundary of the thermocline (defined as the depth at which the change in temperature decreased to less than 1ºC per meter), and thereafter at 5-m intervals to within two m of the bottom (or 50 m). The dissolved oxygen meter reading at 1 m was calibrated at the beginning of a sampling trip using the value from a 60 ml Winkler field titration (Koenings et al. 1987). The DO profile was measured only on the first sampling trip in May because in 2001 we found no major changes in DO profiles during the summer and early fall season.

Secondary Production

Zooplankton are the primary food for sockeye salmon and *Daphnia* sp., in the cladoceran group, are their preferred food within the zooplankton community. By estimating the number and biomass of zooplankton by genus or species throughout the season, we quantified the overall species composition in the lake, and the proportion of numbers and biomass contributed by *Daphnia*. We collected zooplankton samples at all four stations using a 0.5 m diameter, 153 um mesh, 1:3 conical net. Vertical zooplankton tows were pulled from a maximum depth of 50 m, or two m from the bottom of the lake if shallower than 50 m, at a constant speed of 0.5 m sec^{-1}. The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987). Zooplankton samples were analyzed at the ADF&G Commercial Fisheries Limnology Laboratory in Soldotna, Alaska. Identification to genus or species, enumeration, and density and biomass estimates were performed as in 2001 and 2002 (Lewis and Cartwright 2002; Cartwright and Lewis 2004; Koenings et al. 1987). Zooplankton density (individuals per m^2 surface area) and biomass (weight per m^2 surface area) were estimated by species, and total zooplankton density and biomass were estimated by summing across species.

RESULTS

SUBSISTENCE HARVEST ESTIMATE

Of the 446 net sets observed in the Klawock subsistence fishery in 2003, the crew recorded harvest data for 440 sets (Table 2). We sampled 12 of the 19 days the subsistence fishery was open in 2003. Expanding the total sockeye harvest as reported in interviews to account for six missed interviews and for seven days of the fishery that were not sampled, we estimated a total harvest of 5,990 (SE=432; CV=10%) sockeye salmon in the 2003 fishery. Assuming a normal distribution, the 95% confidence interval for the annual harvest was 5,100–6,800 sockeye salmon. This estimate fell within the 95% confidence interval of harvest estimates in the two previous years. Although the fishery was only open for four days in the last week, half of the total sockeye harvest and the highest catch per set occurred during this week (Table 3). The reported subsistence sockeye harvest from ADF&G permits was 3,200 fish, accounting for only 50% of the estimate obtained on the fishing grounds (ADF&G Division of Commercial Fisheries database, 2005).

Table 2.–Estimated daily subsistence harvest for only those days sampled in the two-stage harvest survey of the Klawock Inlet subsistence fishery in 2003; these results are not expanded for days of the week not sampled.

Week	Date	Sets observed	Sets interviewed	Daily sockeye harvest for days in the survey		
				Reported in interviews	Expanded for missed interviews	Std. error
1	7-Jul	10	9	41	46	2
	9-Jul	12	10	80	96	4
	11-Jul	20	20	71	71	0
2	14-Jul	39	39	492	492	0
	16-Jul	15	15	152	152	0
	18-Jul	25	24	158	165	11
3	21-Jul	64	64	270	270	0
	23-Jul	46	45	228	233	9
	24-Jul	38	38	315	315	0
4	28-Jul	74	74	1,058	1,058	0
	29-Jul	37	36	245	252	11
	31-Jul	66	66	884	884	0

Note: The survey crew observed the entire fishing area during each day of the survey and counted all net sets made during that day. For most sets, they conducted an interview to determine total sockeye harvest at the end of the set. If interviews were missed for some sets in a day, the total daily harvest was estimated by dividing the average harvest per interviewed set that day by the proportion of all sets that were interviewed.

Table 3.–Weekly estimates of the number of sockeye salmon harvested, standard errors, and estimated sockeye catch per set in the 2003 Klawock subsistence fishery.

Week	Dates	Expanded weekly estimates			
		Number of sets	Sockeye harvest	Std. error for harvest estimate	Average sockeye catch per set
1	7–11 July	70	354	33	5
2	14–18 July	132	1,348	249	10
3	21–25 July	247	1,363	54	6
4	28–31 July	236	2,925	346	12
Total		685	5,990	432	9

SOCKEYE ESCAPEMENT ESTIMATES

Weir Counts

In 2003, fish counts at the Klawock River weir included 6,276 sockeye (of which 252 were jacks), 48,312 pink, 1,375 chum, and 10,838 coho (of which 4,885 were jacks) salmon. Project crew counted fish through the hatchery raceway at the Klawock River weir from 24 June to 25 October 2003. Although hatchery personnel continued to operate the weir until 7 January 2004, no more sockeye salmon and no other fish except a few coho salmon were counted after 25 October 2003 (Appendix A). Carcasses of 488 sockeye salmon that had not yet spawned were recovered from the weir and subtracted from the total count, leaving an adjusted total count of 5,788 live sockeye salmon that entered the lake in 2003. By 31 July, the date the Klawock subsistence fishery closed, only 5% of the total sockeye escapement had entered the lake (Figure 3). During August, over 70% of the sockeye escapement was counted through the weir. A flood on 2 September breached the weir and an unknown number of fish passed the weir undetected (Figure 3). In addition, the water level was near flood levels between 11 and 27 September (Appendix A).

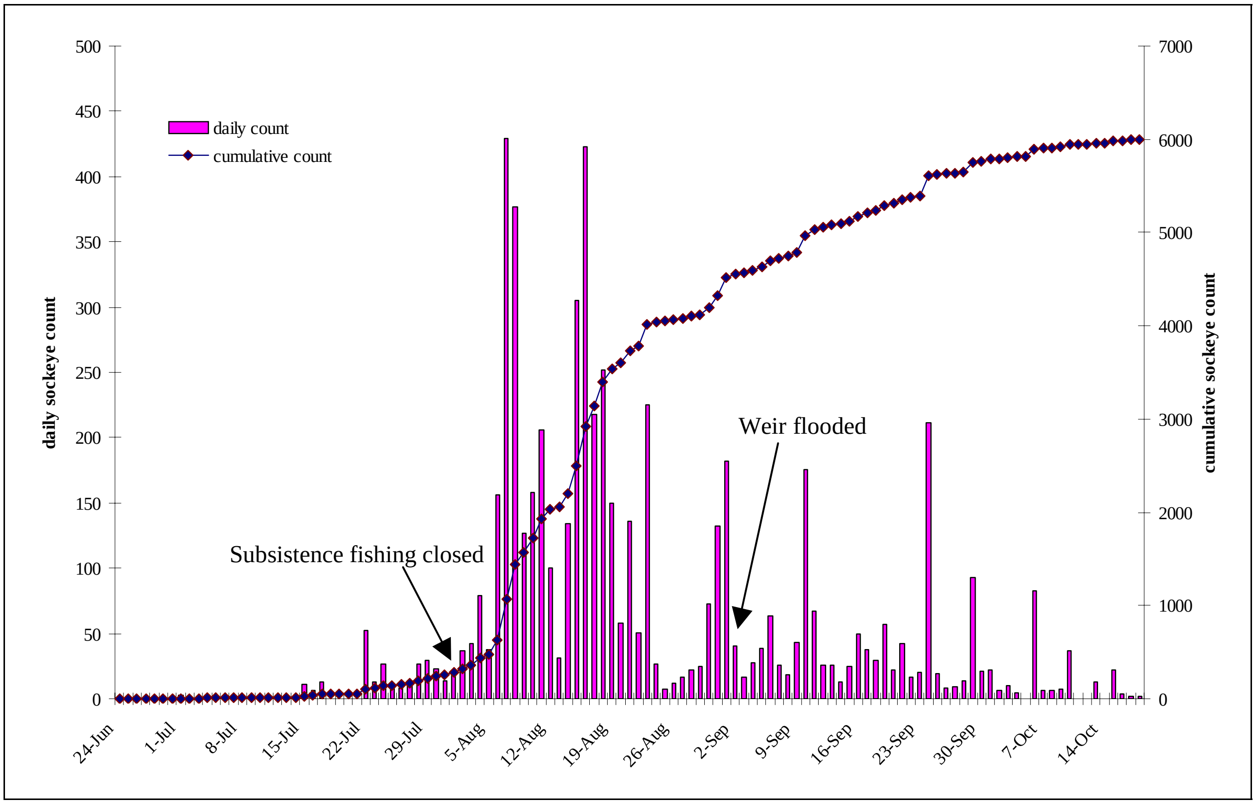


Figure 3.–Weir count and timing of sockeye salmon passing through the Klawock River weir via the hatchery raceway in 2003. The subsistence fishery closed on 31 July, and a flood breached the weir on 2 September (arrows).

Weir Mark-Recapture Estimate

At the weir, the crew marked 21% of all sockeye salmon they counted (Table 4). A secondary mark was used to stratify marking by time, based on run timing in previous years. However, these strata did not correspond well to the natural timing of the run in 2003. So, prior to analysis, we combined the first two and last two marking strata because the first and last strata were disproportionately small. The first combined stratum included 4,496 sockeye salmon counted at the weir between 24 June and 31 August, or about 75% of the total counted escapement. The second combined stratum included 1,530 sockeye salmon counted at the weir between 1 September and 25 October, or the last 25% of the counted sockeye escapement.

The crew concentrated their recapture sampling efforts at Threemile Creek, sampling a total of 940 sockeye spawners on 13 sampling events between 19 August and 8 October (Table 4). They sampled somewhat less intensively at Inlet and Halfmile creeks, capturing totals of 251 fish in seven events (26 August–9 October) at Inlet Creek and 552 fish in six events (8 September–8 October) at Halfmile Creek. The crew sampled in Hatchery Creek on just two events in October, and caught only 16 fish. In all locations and all sampling events, a total of 1,759 sockeye spawners were sampled, of which 98 (6%) were marked. The percentage of marked fish in the total samples was consistently 5–6% from each stream (Table 4).

Table 4.–Number of sockeye salmon marked at the weir for each marking period, and number of recoveries of marked fish by stream and marking stratum in Klawock Lake 2003. The number of fish passed through the weir during each marking period is included for comparison.

Marking at weir					Marks recaptured on spawning grounds					
Marking stratum	**Dates**	**Number passed**	**Number marked**	**Percent marked**	**Threemile**	**Inlet**	**Halfmile**	**Hatchery**	**All**	**Percent of marks recovered**
1	24 Jun–31 Aug	4,496	853	19%	47	12	20	0	79	9%
2	1 Sep–25 Oct	1,530	419	27%	7	4	7	1	19	5%
Total		6,026	1,272	21%	54	16	27	1	98	8%
				Total sampled	940	251	552	16	1,759	
				Percent of total sample with marks	6%	6%	5%	6%	6%	

From these mark and recapture data, we obtained a pooled Petersen estimate of 22,900 sockeye salmon (CV=9%; 95% CI: 19,400–28,500 fish) for Klawock Lake in 2003. Using the SPAS program, we were unable to detect violations of the assumption that capture probabilities were equal for fish marked in the first event (i.e. at the weir), because the goodness-of-fit test statistic for equal proportions was not significant ($p = 0.85$). Given the unequal sampling effort and times between the four recapture strata, we most likely violated the assumption for complete mixing or equal probability of capture in the second event (i.e. on the spawning grounds), indicated by a significant goodness-of-fit test statistic for complete mixing ($p < 0.001$). The maximum-likelihood Darroch estimate, with two marking and four recapture strata, was 23,500 fish (CV=18%). Because at least one of the consistency tests passed (i.e. was non-significant), and there was not a large difference between the pooled Petersen and Darroch estimates, we decided to use the pooled Petersen estimate to increase precision. Consequently, the final 2003 sockeye escapement estimate was 21,300 sockeye salmon, after subtracting 500 dead sockeye salmon on the weir and 1,060 fish taken for brood stock by the Prince of Wales Hatchery.

To determine if handling mortality during sampling and marking contributed to the discrepancy between the weir count and the mark-recapture estimate in previous years, we held 104 sockeye salmon for 24 hours after they were marked (see discussion in Cartwright and Lewis 2004). None of these fish died during the holding period.

Stream Mark-Recapture Estimates and Visual Surveys

In addition to the weir mark-recapture study to estimate total sockeye escapement into the lake, we also conducted mark-recapture studies in Halfmile and Threemile Creeks to separately estimate the population of sockeye spawners in each stream. In Halfmile Creek, we marked and released a total of 262 fish at the mouth of the stream between 9 September and 8 October. We sampled a total of 311 fish in the stream between 16 September and 15 October. Only five marked fish were recovered (Table 5). This number of recaptures was too small to yield a meaningful estimate of sockeye spawners in Halfmile Creek. Likewise, after marking and releasing 104 sockeye salmon at the mouth of Threemile Creek between 9 and 30 September, and later sampling 168 sockeye salmon in this creek to look for marks between 16 September and 8 October, only four marked fish were recovered (Table 6). Again, this number of recaptures was too small to yield a reliable sockeye population estimate in Threemile Creek in 2003.

Table 5.–Sample sizes in marking and recapture strata and numbers of marked fish caught in recapture sampling in Halfmile Creek, a tributary of Klawock Lake, in 2003. Marking was conducted at the mouth of the stream; recapture sampling was conducted in the stream.

			Number of marked fish observed by recapture event (date)					
Marking stratum (date)	**Mark used**	**Number marked**	**1 (16 Sep)**	**2 (1 Oct)**	**3 (8 Oct)**	**4 (15 Oct)**	**All events**	**Percent of marks recovered**
1 (9 Sep)	Square	40	2	0	0	0	2	5%
2 (15 Sep)	Double square	30	-	0	0	0	0	0%
3 (30 Sep)	Adipose	74	-	-	0	0	0	0%
4 (7–8 Oct)	Caudal	118	-	-	-	3	3	3%
		262	2	0	0	3	5	2%
Number of fish sampled for marks			55	127	68	61	311	
Percent of sample with marks			4%	0%	0%	5%	2%	

Table 6.–Sample sizes in mark and recapture strata and numbers of marked fish caught in recapture sampling in Threemile Creek, a tributary of Klawock Lake, 2003. Marking was conducted at the mouth of the stream; recapture sampling was conducted in the stream.

			Number of marked fish observed by recapture event (date)				
Marking stratum (date)	**Mark used**	**Number marked**	**1 (16 Sep)**	**2 (1 Oct)**	**3 (8 Oct)**	**All events**	**Percent of marks recovered**
1 (9 Sep)	Square	26	1	0	0	1	4%
2 (15 Sep)	Double square	31	-	0	0	0	0%
3 (30 Sep)	Adipose	47	-	-	3	3	6%
		104	1	0	3	4	2%
Number of fish sampled for marks			91	33	44	168	
Percent of sample with marks			1%	0%	7%	2%	

The major sockeye spawning tributaries of Klawock Lake were surveyed several times between the end of July and mid-October. No spawners were observed in the streams before 25 August, although some were detected earlier in deeper water off the stream mouths (Table 7). Threemile Creek had the highest counts overall, and counts remained high in that stream from 27 August through 7 October. Hatchery Creek had the lowest counts through the season, followed by Halfmile Creek. The highest counts of spawners overall were obtained on 8 September, mostly in Threemile Creek, and 15 September, mostly in Inlet Creek. Visual counts are known to be biased low, however, and we may not have captured the magnitude of peak abundance in late August through September. Nevertheless, the 2003 stream counts were similar to counts in the previous two years (Lewis and Cartwright 2002; Cartwright and Lewis 2004).

Table 7.–Visual counts of sockeye spawners and carcasses in Klawock Lake's four main inlet streams obtained during foot surveys of each stream in 2003.

Date	Threemile		Halfmile		Inlet		Hatchery	
	live	dead	live	dead	live	dead	live	dead
29-Jul	0	0	0	0	0	0	0	0
13-Aug	0	0	0	0	0	0	0	0
14-Aug	0	0	0	0	0	0	0	0
15-Aug	0	0	0	0	0	0	0	0
19-Aug	0	0	0	0	0	0	0	0
20-Aug	0	0	0	0	0	0	0	0
22-Aug	0	0	0	0	0	0	0	0
25-Aug	7	0	0	0	7	0	8	0
26-Aug	0	0	0	0	35	1	0	0
27-Aug	169	0	0	0	0	0	0	0
8-Sep	476	5	128	1	0	0	0	0
15-Sep	0	0	0	0	508	12	0	0
17-Sep	0	0	0	0	0	0	22	0
19-Sep	199	30	0	0	0	0	0	0
22-Sep	0	0	121	3	128	22	0	0
29-Sep	0	0	0	0	60	4	0	0
30-Sep	0	0	156	8	0	0	0	0
2-Oct	0	0	0	0	30	2	0	0
3-Oct	242	20	0	0	0	0	80	5
7-Oct	145	15	105	35	0	0	0	0
9-Oct	0	0	0	0	30	1	97	3
14-Oct	20	0	70	1	0	0	0	0

SOCKEYE ADULT AGE AND LENGTH COMPOSITION

In 2003, as in previous years, analysis of the sockeye spawning population age structure in Klawock Lake showed most fish returning at age-5. The dominant age classes were age-1.3 (60%; CV=4%) and age-2.2 (26%; CV=7%; Table 8). In 2003, as in the previous two years, most returning adults had one year of freshwater growth as juveniles. Freshwater age appeared to have little relation to adult size. The mean fork length of age-1.2 fish was only slightly less than for age-2.2 fish, for both sexes, but there was no meaningful difference in lengths between age-1.3 fish and age-2.3 fish. However, ocean age was related to adult size: fish with three ocean years were consistently larger than those with two ocean years (Table 9). In 2003, age-1.3 fish represented the largest proportion of the escapement each week, except for the week of 27 July and 12 October (Table 10).

Table 8.–Age composition of sockeye salmon by brood year, age, and sex, 2003.

Brood Year:	2000	1999	1998	1999	1998	1997	Total
Age:	1.1	1.2	1.3	2.1	2.2	2.3	
Male							
Sample size	5	27	146	17	37	6	238
Percent	1%	5%	29%	3%	7%	1%	47%
Std. error	0.4%	1.0%	2.0%	0.8%	1.2%	0.5%	2.2%
Female							
Sample size		15	153		94	8	270
Percent	0%	3%	30%	0%	19%	2%	53%
Std. error	0.0%	0.8%	2.0%	0.0%	1.7%	0.6%	2.2%
All Fish							
Sample size	5	42	299	17	131	14	508
Percent	1%	8%	59%	3%	26%	3%	100%
Std. error	0.4%	1.2%	2.2%	0.8%	1.9%	0.7%	0%
Percent by age class, weighted by escapement per week	1%	8%	60%	3%	26%	3%	100%
Total number in escapement, by age class	157	1,744	12,699	602	5,500	598	21,300

Table 9.–Mean fork length (mm) of sockeye salmon in 2003 Klawock Lake escapement by sex, brood year, and age class.

Brood year:	2000	1999	1998	1999	1998	1997
Age:	1.1	1.2	1.3	2.1	2.2	2.3
Male						
Mean length (mm)	401	499	573	442	514	577
Std. error	5.8	8.3	1.9	4.2	3.9	12.2
Sample size	5	27	146	14	37	6
Female						
Mean length (mm)		511	556		515	555
Std.error		10.8	1.8		2.2	5.5
Sample size		15	151		94	8
All fish						
Mean length (mm)	401	503	565	442	514	564
Std. error	5.8	6.6	1.4	4.2	1.9	6.6
Sample size	5	42	297	14	131	14

Table 10.–Weighted percent of sockeye salmon in each age class by week from 13 July to 12 October in Klawock Lake in 2003. The percent age compositions were weighted by the weekly weir counts.

Week beginning	1.1	1.2	1.3	2.1	2.2	2.3	Weekly count
13-Jul	0%	40%	50%	0%	10%	0%	51
20-Jul	0%	33%	56%	0%	0%	11%	124
27-Jul	0%	20%	20%	10%	50%	0%	190
3-Aug	0%	6%	65%	0%	26%	3%	1,271
10-Aug	1%	8%	60%	2%	25%	3%	1,412
17-Aug	0%	6%	62%	3%	25%	5%	1,112
24-Aug	3%	5%	54%	7%	29%	2%	202
31-Aug	3%	9%	50%	9%	29%	0%	521
7-Sep	2%	10%	55%	4%	29%	0%	397
14-Sep	0%	0%	54%	4%	35%	8%	197
21-Sep	0%	10%	76%	0%	14%	0%	337
28-Sep	0%	5%	75%	0%	20%	0%	175
5-Oct	0%	12%	65%	0%	24%	0%	142
12-Oct	0%	0%	33%	33%	33%	0%	39
Total							6,170

Sockeye Smolt Age, Length, and Weight Compostion

Of 608 sockeye smolt captured in the fyke net and screw trap, 299 smolt were sampled for scales (age), length, and weight; age was determined for 284 of those fish sampled (Table 11). Age-1 smolt comprised an estimated 62% and age-2 smolt comprised an estimated 33% of sockeye smolt emigration from Klawock Lake in 2003; the remaining 5% of the sampled smolt were fish for which age could not be determined. The length distribution of age-1 and age-2 smolt showed little overlap, with a mode of 91 mm for age-1 fish and a mode of 130 mm for age-2 fish (Figure 4). Length distributions were similar to age-1 smolt sampled in 1987, 1988, and 1995 (Lewis and Zadina 2001). Age-2 smolt from these earlier years were smaller, on average, than those sampled in 2003, but the differences may not be meaningful (Lewis and Zadina 2001).

Table 11.–Number and estimated percentages of sockeye smolt at age-1 and age-2, and their mean lengths and weights, emigrating from Klawock Lake in 2003.

Age	Number at age	Estimated percent of total emigration at age	Mean length in mm (SE)	Mean weight in g (SE)
1	186	62	88 (0.5)	6.2 (0.1)
2	98	33	124 (1.1)	17.3 (0.5)
ND	15	5	-	
All	299			

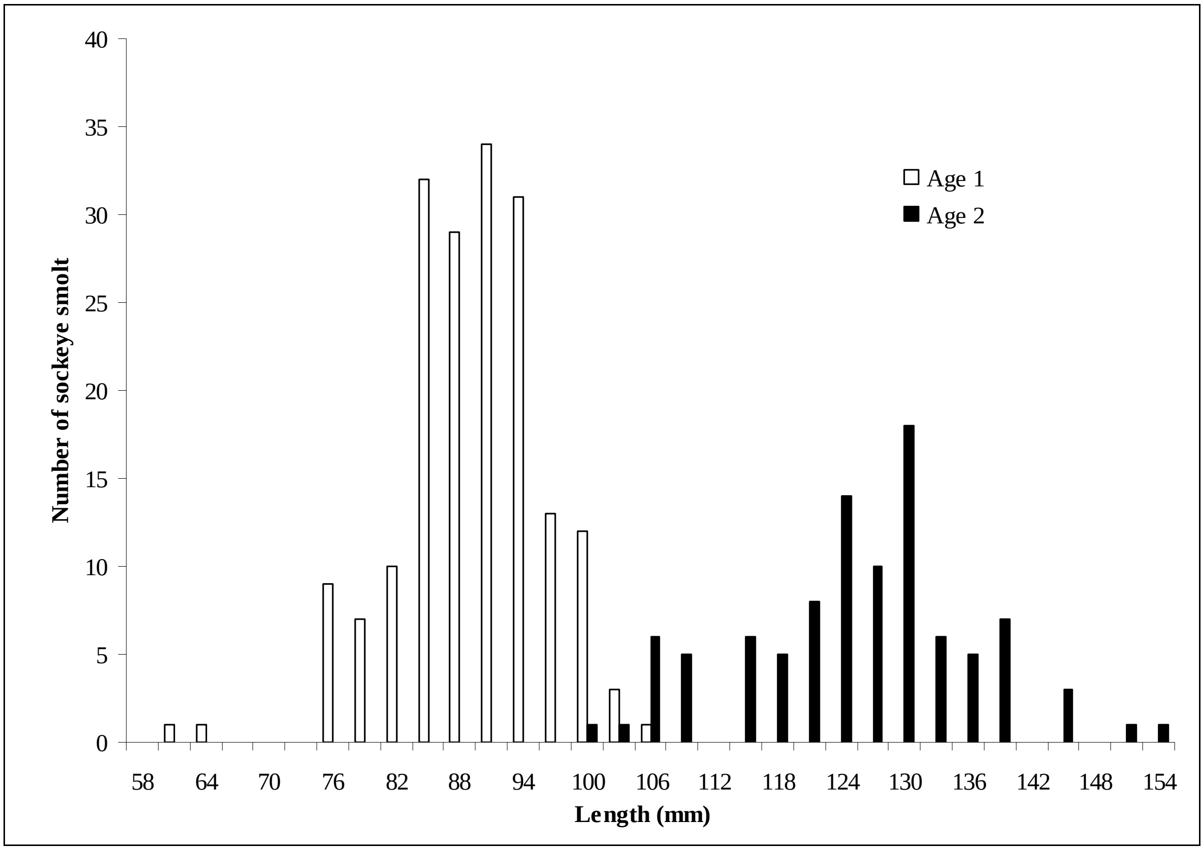


Figure 4.–Length distribution, by age, of sockeye smolt emigrating from Klawock Lake in 2003.

SOCKEYE FRY POPULATION ESTIMATE

We conducted a hydroacoustic survey and mid-water trawl sampling on 28 July 2003, and we estimated about 400,000 (SE=49,000, CV=12%) total targets between from those targets recorded between –40 dB and –68 dB. Species apportionment was based on results of ten 20-min mid-water trawl tows, with a total sample of 42 small pelagic fish (34 sockeye fry, 4 sticklebacks, and 3 sculpins; Table 12). All sockeye salmon captured in the tows were age-0 fry, whose mean length was 42.1 mm and mean weight was 0.8 g (Table 13). Sockeye fry comprised 81% of fish in all trawl samples combined; thus we estimated a population of 320,000 sockeye fry in 2003. Using the Bayesian approach, the posterior mean of the distribution of the proportion of sockeye targets (p) was 77%, and the mean estimate of total targets (T) was 395,500 (Table 14). The product of these posterior means of p and T produced an estimate of about 300,000 sockeye fry (95% credible interval 210,000–400,000), which we consider our final estimate. This estimated sockeye fry population was similar in size to populations estimated in previous years, despite differences in type of estimate, time of year, number of tows, and type of acoustic gear (Table 3 in Cartwright and Lewis 2004). The sockeye fry density was three fry per 100 m^2 (95% credible interval of 2–4 fry per 100 m^2). Considering all sources of uncertainty, we concluded that the posterior coefficient of variation for the sockeye fry estimate was less than 16% (posterior standard deviation divided by posterior mean number of sockeye fry). This coefficient of variation was higher than our stated objective for hydroacoustic sampling (CV <10%).

Table 12.–Summary of Klawock Lake mid-water trawl results in 2003 by tow, depth (m), time duration (min), species, and sample size.

Tow number	Basin	Depth (m)	Duration of tow (min)	Sockeye fry age-0	Stickleback (all ages)	Sculpin (all ages)
1	B	Surface	20	0	0	0
2	B	10	20	2	0	0
3	B	10	20	3	0	0
4	B	12	20	0	0	0
5	B	12	20	11	0	0
6	A	12	20	2	2	0
7	A	10	20	13	1	1
8	A	Surface	20	0	1	0
9	A	10	20	0	1	1
10	A	12	20	3	0	1
Total				34	5	3

Table 13.–Mean length and weight, by species, of small pelagic fish caught in mid-water trawl samples in Klawock Lake in 2003.

Species	Sample size	Mean length mm (SE)	Mean weight g (SE)
Sockeye fry age-0	34	42.1 (1.3)	0.8 (0.1)
Stickleback	5	31.6 (8.0)	0.7 (0.6)
Sculpin	3	29.7 (2.8)	0.3 (0.0)
Total	42		

Table 14.–Bayesian estimates of the underlying population proportions of sockeye fry from trawl samples taken in Klawock Lake during the 2003 fry survey.

Parameter/estimate	Sample size	Mean	Std error	2.5 Percent	97.5 Percent	Median
p_1	2	0.789	0.100	0.572	0.955	0.800
p_2	3	0.796	0.095	0.591	0.959	0.802
p_3	11	0.835	0.080	0.661	0.976	0.841
p_4	4	0.735	0.106	0.484	0.901	0.747
p_5	15	0.804	0.075	0.643	0.932	0.811
p_6	1	0.738	0.120	0.450	0.912	0.757
p_7	2	0.713	0.126	0.397	0.893	0.733
p_8	4	0.769	0.096	0.557	0.927	0.778
p_μ		0.77	0.072	0.61	0.89	0.777
Total target estimate		395,500	48,720	299,600	492,800	395,300
Total sockeye fry estimate		304,500	46,950	213,800	395,900	305,000

Note: The proportion estimates were based on eight trawl samples (two trawl tows yielded no fish and were dropped from the analysis). Distributions of the proportions of sockeye fry in simulations for each trawl sample are represented by the posterior mean proportions (p_i), standard errors, and lower (2.5%) and upper (97.5%) credible intervals for each sample and an overall proportion (p_μ) for the whole lake. The Bayesian estimate of total hydroacoustic targets with standard error and lower (2.5%) and upper (97.5%) credible intervals is also shown. The total sockeye fry population was estimated as the product of p_μ and the total target population.

Separate from the wild sockeye fry population, the Prince of Wales Hatchery released a total of 365,000 hatchery-produced sockeye fry: 244,00 emergent (or unfed) sockeye fry were released between 28 February and 12 March 2003, and 120,000 fed sockeye fry were released between 25 March and 1 April 2003. These fry were produced from wild broodstock harvested from Threemile and Halfmile Creeks, and all fry were released into Threemile Creek.

LIMNOLOGY SAMPLING

Light, Temperature, and Dissolved Oxygen Profiles

In 2003, the mean euphotic zone depth (EZD) was 4.1 m across both lake basins between 14 May and 23 October (Table 15). The euphotic zone depth varied little between the basins, with a range over the season of less than 0.5 m in Basin B, and about 1.5 m in Basin A. The seasonal mean euphotic depth has also varied little across years in Klawock Lake since 1986, with the 2003 value in the middle of the range of values for this period (Table 16).

Table 15.–Euphotic zone depths (EZD) in Klawock Lake Basins A and B in 2003, estimated from light intensity vs. depth profiles at each indicated sampling date, with means across basins and sampling dates.

Date	Basin A	Basin B	Mean
14-May	4.5	4.0	4.3
25-Jun	4.2	4.2	4.2
31-Jul	4.9	4.2	4.5
5-Sep	3.4	4.2	3.8
23-Oct	3.7	3.8	3.7
Seasonal mean	4.1	4.1	4.1

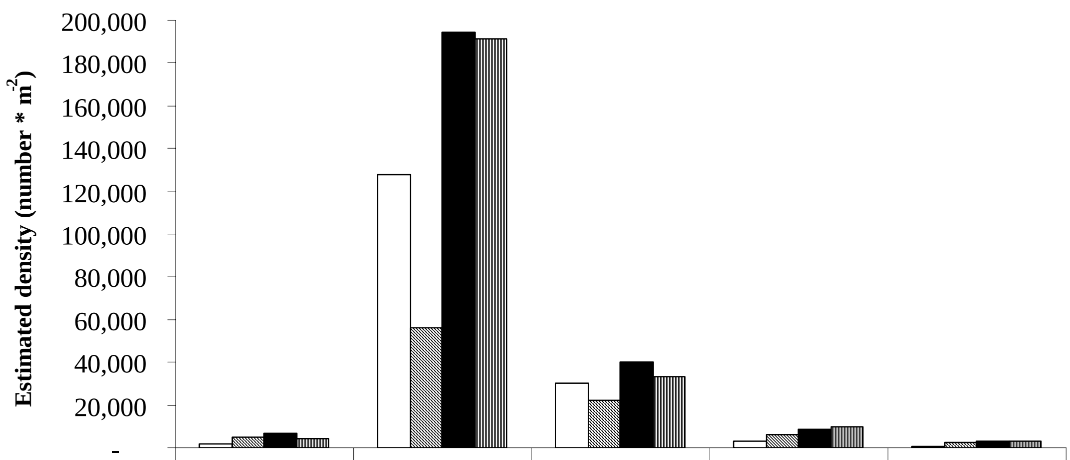
Table 16.–Seasonal mean euphotic zone depths (m) across stations and sampling dates in Klawock Lake in 1986–1988 and 2000–2003.

Year	Seasonal mean (m)
1986	4.5
1987	3.9
1988	3.9
2000	4.5
2001	4.3
2002	5.3
2003	4.1

Typical of most sockeye lakes in Southeast Alaska, Klawock Lake is dimictic, with temperature stratification developing during the spring and summer. The near-surface temperature (1 m) peaked at the end of July at 17.5°C in Basin A and 18.8°C in Basin B (Appendix C). The top boundary of the thermocline in Basin A was always deeper than Basin B with the exception of 5 September when they were both 10 m (Appendix C). Unfortunately, the crew did not measure temperature at critical depths to define the lower boundary of the thermocline on some sample dates, so we were unable to define the range of the thermocline for 2003. In Basin A, the dissolved oxygen (DO) levels in 2003 ranged from 96% saturation at 1 m on 23 October to 48% saturation at 20 m on 5 September (Appendix D). The DO readings in Basin B were similar, ranging from 96% saturation at 1 m on 23 October to 74% at 45 m on 5 September (Appendix D).

Secondary Production

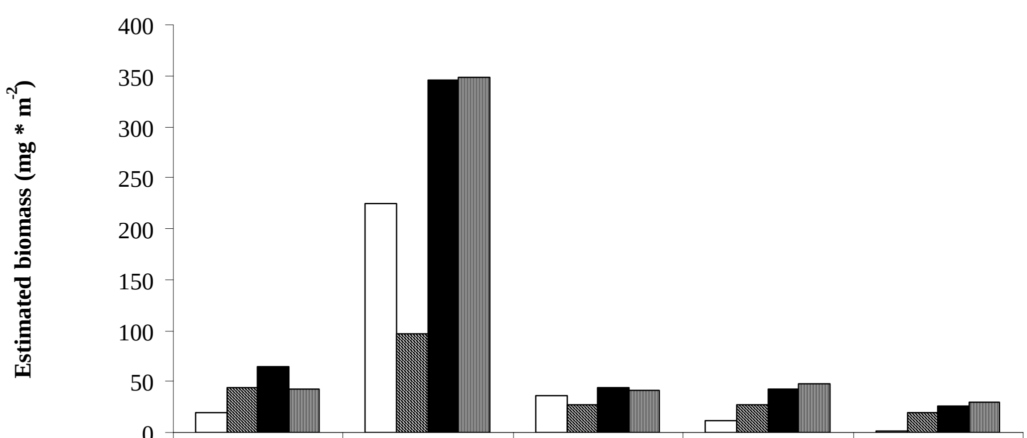
In 2003, the zooplankton community was dominated by *Cyclops* sp. (Figure 5), which comprised about 80% of the total community numerical density (Appendix E), an increase from 69% in 2002 and 57% in 2001. In comparison, the other copepod group, *Epischura* sp., and the cladocerans, *Daphnia rosea*, *Bosmina* sp., and *Holopedium* sp., were present in much lower numbers (Figure 5; Appendix E). *Daphnia rosea*, the most desirable prey species for sockeye fry contributed a slightly greater proportion to the total zooplankton biomass than to numerical density, because of its relatively large size (Figures 5 and 6; Appendices E and F). *Cyclops* sp., although smaller, contributed the largest proportion of the total zooplankton biomass, 64% on average across sampling stations, due to its greater numerical abundance (Figures 5 and 6; Appendices E and F).



	Epischura	Cyclops	Bosmina	Daphnia r.	Holopedium
Station A	1,796	127,716	30,135	2,971	662
Station C	4,814	56,048	22,067	6,356	2,208
Station B	6,580	194,459	40,301	8,533	2,929
Station D	4,330	191,445	33,141	9,778	3,141

Taxon

Figure 5.–Seasonal mean zooplankton density (number m^{-2}) in Klawock Lake in 2003, by species and station. Station A and C are in Basin A and Station B and D are in Basin B.



	Epischura	Cyclops	Bosmina	Daphnia r.	Holopedium
Station A	19	224	36	11	2
Station C	44	97	28	27	19
Station B	65	346	43	43	26
Station D	42	349	41	47	30

Taxon

Figure 6.–Seasonal mean zooplankton biomass estimates (mg m^{-2}), by species and station in Klawock Lake in 2003.

DISCUSSION

ASSESSMENT OF ESCAPEMENT

The main objective for the 2001–2003 study was to accurately estimate the sockeye spawning population in Klawock Lake, by counting sockeye salmon at a weir on the outlet stream and verifying the count using mark-recapture studies. In 2002, the weir count fell within the 95% confidence interval of the mark-recapture estimate (Cartwright and Lewis 2004), providing reasonable certainty that the count and estimate were accurate. No major high water events occurred in 2002 in the Klawock watershed during the time sockeye salmon were returning to the lake. However, in 2001 and 2003, the mark-recapture estimates were two to four times higher than the weir counts (Lewis and Cartwright 2002). In both these years, high water breached the top of the weir on several occasions. In these circumstances, we had to rely on the mark-recapture estimate as the best measure of sockeye escapement. The weir structure was improved in 2004 by decreasing the picket spacing, increasing the angle of the face of the weir, and adding a boom log to prevent debris from damaging the weir. Even so, high water in the river does exceed the height of the weir at least once a season in most years. We regard a mark-recapture study as a necessary component of this or any weir project intended to estimate salmon escapement.

In 2003, one of our objectives was to separately estimate the sockeye population in Halfmile and Threemile Creeks. However, we were unable to maintain a weekly sampling schedule due to heavy rains in late August and September, and so we did not recover adequate numbers of marks to form reliable estimates (Seber 1982). We may have also missed the peak spawning period in these streams. Consequently, we did not accomplish this objective. Even so, we think this objective is worth pursuing in future years. Consistent sampling every five to seven days in each stream is important to maintain adequate sample sizes and mark-recoveries, but is often challenging due to weather and dramatic increases in stream flow. Because this study requires intensive marking distinct from marks applied at the weir, we began using individually numbered tags instead of fin clips or opercular punches in 2004. Tags reduce the number of different marks that must be applied to fish, and simplify data collection procedures. Even if precision for the separate stream population estimates is somewhat lower, we expect that the sum of estimated spawning population in each stream should track the whole-lake estimate (weir count or weir mark-recapture estimate) within 10–15%.

ASSESSMENT OF THE SUBSISTENCE FISHERY

A consistent harvest of about 6,000 sockeye salmon was taken in the subsistence fishery in Klawock Inlet, the largest subsistence fishery in Southeast Alaska, in all three years of our study (2001–2003; Lewis and Cartwright 2002; Cartwright and Lewis 2004). If we regard the total sockeye run in Klawock Inlet as the sum of subsistence harvest and escapement, subsistence harvest comprised 30–45% of the total sockeye run in 2001–2003. The total sockeye harvest reported by holders of ADF&G subsistence permits for Klawock Inlet was consistently lower, by 33–47%, than our 2001–2003 harvest estimates using on-site interviews in the fishery. Because accurate harvest estimates are valuable to our understanding and management of this sockeye stock, we recommend that the subsistence fishery monitoring be continued.

We estimated total sockeye runs to Klawock Inlet of about 20,400 fish in 2001, 18,600 fish in 2002, and 29,000 fish in 2003. The run size was fairly consistent in these three years; the largest run in 2003 was based in large part on a mark-recapture estimate that was several times higher than the weir count. Three years of information is not enough to assess the status of this stock or confidently evaluate the trends in returns to Klawock Inlet. Unfortunately, subsistence harvest and escapement estimates for years prior to 2001 are so unreliable and poorly documented that a comparison between the earlier estimates and those from 2001–2003 would be misleading at best (Cartwright and Lewis 2004).

Because the subsistence fishery is only open during the early part of the sockeye run in July, a disproportionate number of sockeye salmon are harvested at the beginning of the run. In 2003, we observed that about a third of the total sockeye run, represented by the sum of subsistence harvest estimates and escapement weir counts, had entered Klawock Inlet by the end of July, but only 5% of the run had entered Klawock Lake by this time. In 2001 and 2002, about half of the total sockeye run had entered Klawock Inlet by the end of July, but lake escapement to that date comprised less than 10% of the total run. If the early-run fish form one or more reproductively isolated sockeye populations in Klawock Lake, the timing of the subsistence harvest could be a problem. Reproductively isolated sockeye sub-populations have been identified in single lake systems (Ramstad et al. 2003). Members of the same sub-population often enter the system at the same time and have discrete phenotypic and behavioral traits (Quinn et al. 1999; Woody et al. 2000). This finely-tuned spawning timing among several sub-populations within a single sockeye stock optimizes fry survival (Brannon 1967; Quinn et al. 1999). Therefore, the existing fishing schedule during the Klawock sockeye run could result in the unintended consequence of disproportionately reducing the size and productivity of one or more sub-populations. The use of individually-numbered tags in the mark-recapture study will help us examine the relationship between time of entry into the lake and time or location of spawning.

ASSESSMENT OF FRESHWATER PRODUCTION

Obtaining a reliable estimate of the sockeye fry population in Klawock Lake has been difficult, especially determining species apportionment. Small pelagic fish are difficult to capture in this lake with mid-water trawl gear. In 2002, doubling the number of tows in the October survey from the number in the July survey increased the sample size by only 12 more fish (*n*=40 fish in July; *n*=52 fish in October; Cartwright and Lewis 2004). Because we do not have a lot of confidence in the Klawock Lake sockeye fry estimates we obtained in 2001–2003, we do not feel continued fry surveys are worthwhile, unless substantial improvements in methods can be made. In order to achieve better species apportionment estimates, for example, we could increase the amount of trawl effort, extending sampling over several nights. We would also recommend the survey be conducted in Basin B to avoid the extensive buoy system in Basin A associated with the hatchery. Basin B would have to be surveyed in October, because sockeye fry migrate from Basin A to Basin B during the summer (Lewis and Cartwright 2002; Cartwright and Lewis 2004). However, fry are bigger in October and may be more able to avoid the trawl net; size bias in sampling for small pelagic fish with trawl gear has been documented (Paul Rankin personal communication, fisheries biologist, Department of Fisheries and Oceans, British Columbia). Increasing sampling effort and improving sampling methods for fry assessment may be worthwhile if the population of sockeye spawners in Klawock Lake should change substantially. We would like to know the response in the offspring fry population to a large increase or decrease in the spawner population.

We have some evidence that a relatively high proportion of sockeye fry hold over for a second year in Klawock Lake, in comparison with other Prince of Wales Island lakes. In 2003, only 8%, 5%, and 25% of adults returning, respectively, to Hetta, Salmon Bay, and Luck Lakes had two years of freshwater growth, compared with 32% in Klawock Lake (Cartwright et al. 2005; Cartwright et al. 2006). Studies with artificially-planted sockeye fry in Alaskan lakes have shown that at high sockeye fry densities, food availability limits growth to the point that fry remain in the lake for an additional year (Koenings and Burkett 1987).

LIMITATIONS OF SOCKEYE PRODUCTION IN KLAWOCK LAKE

Although difficult to measure, we hypothesize that the production of sockeye salmon in Klawock Lake has declined substantially in the last century. As stated in the introduction, this decline appears to be initially due to high exploitation of the stock by commercial fisheries in the early 1900s. However, because we do not know how many Klawock Lake sockeye salmon were harvested in the mixed stock commercial fisheries, we cannot assess the effects of commercial harvest on the Klawock Lake stock. From the subsistence fishery harvest estimates in the last three years, we do know that about 30–45% of all sockeye salmon returning to Klawock Inlet were harvested in this easily accessible subsistence fishery. Residents of Klawock have also told us that additional sockeye salmon are harvested in August during the subsistence chum fishery but are not reported because the sockeye fishery is closed.

Declines in sockeye production are probably due in part to human perturbations in the drainage and the resulting loss or degradation of sockeye spawning and rearing habitat. The watershed has been intensively logged, which has increased sediment loads and reduced or de-stabilized large woody debris in the spawning streams. Logging roads with dysfunctional culverts block many stream reaches to fish passage (Klawock Watershed Assessment, USDA Forest Service Craig Ranger District unpublished agency report 2002). The sockeye egg-to-fry survival most likely has declined due to the habitat disturbances in the spawning beds (Scrivener and Brownlee 1989). These spawning streams have also been altered by development of subdivisions in their floodplains, and water removals by the City of Klawock.

As stated in the introduction, hatchery managers could not distinguish hatchery-produced from wild sockeye returns to the lake before 1999, but they assumed that the stocking program contributed substantially to commercial and subsistence sockeye harvests and sockeye escapement. In 1999, the hatchery began thermal otolith marking. From 2003 to 2005, we have collected otoliths from sockeye fry, smolt, and returning adults to estimate the hatchery contribution to the total sockeye stock. In all life history stages sampled, 0–2.7% of the fish had thermally marked otoliths. Our estimates showed that very few stocked sockeye fry survived to mid-season in the year they were stocked and even fewer left the lake as smolts the next year. After examining adult sockeye otolith samples from the 1999 and 2000 brood years, we estimated that the number of hatchery-produced sockeye adults returning to the lake did not even replace the number taken for broodstock (M. Cartwright, ADF&G Division of Commercial Fisheries, unpublished data).

If the Klawock Lake sockeye runs are depressed, and the sockeye fry stocking program did not produce more fish, what do we do next? Identifying the factors that may limit sockeye production in freshwater is complex due to multiple forces at work in the Klawock system. For instance, how much does the dysfunctional spawning habitat or barriers such as road culverts reduce production? Is over-harvest in subsistence or commercial fisheries in nearby areas limiting the ability of this stock to reproduce itself and increase in numbers? To begin with, we recommend a systematic analysis of the limnological information we have already collected in the past 20 years, which may reveal specific factors or relationships that limit sockeye production. Rather than continuing to stock sockeye fry with a remote chance of success in compensating for reduced wild production, we should be taking a hard look at why the wild stock has declined. We encourage the fishery managers and subsistence fishery participants to focus their efforts on strategies to increase the number of sockeye salmon returning to Klawock Inlet that have the highest chance of success.

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APPENDICES

Appendix A.–The 2003 daily counts of salmon by species through Klawock Lake weir via the Klawock hatchery raceway and the daily water level of Klawock River. The depth gauge at the Klawock hatchery measures total elevation above sea level. Water depths shown in the table have been adjusted by subtracting 28.5 ft (the elevation of the riverbed at the gauge site) from the depth gauge readings. This adjustment was not made in previous reports.

Date	Sockeye adults	Sockeye jacks	Total sockeye salmon	Cumulative sockeye salmon	Pink	Chum	Coho	Coho jacks	Water depth (m)
24-Jun	0	0	0	0	0	0	0	0	0.9
25-Jun	1	0	1	1	0	0	0	0	0.9
26-Jun	0	0	0	1	0	0	0	0	0.9
27-Jun	1	0	1	2	0	0	2	0	0.9
28-Jun	0	0	0	2	0	0	0	0	0.9
29-Jun	0	0	0	2	0	0	0	0	0.9
30-Jun	0	0	0	2	0	0	0	0	0.8
1-Jul	3	0	3	5	0	0	0	0	0.8
2-Jul	0	0	0	5	0	0	0	0	0.8
3-Jul	1	0	1	6	0	0	0	0	0.9
4-Jul	3	0	3	9	0	0	0	0	0.9
5-Jul	1	0	1	10	0	0	0	0	0.9
6-Jul	1	0	1	11	0	0	0	0	0.9
7-Jul	2	0	2	13	0	0	0	0	0.9
8-Jul	1	0	1	14	0	0	0	0	0.9
9-Jul	0	0	0	14	0	0	0	0	0.8
10-Jul	0	0	0	14	0	0	0	0	0.8
11-Jul	2	0	2	16	0	0	0	0	0.8
12-Jul	0	0	0	16	0	0	1	0	0.8
13-Jul	0	0	0	16	0	0	0	0	-
14-Jul	0	0	0	16	0	0	0	0	0.9
15-Jul	10	2	12	28	0	0	0	0	0.8
16-Jul	5	1	6	34	0	0	0	0	0.8
17-Jul	13	0	13	47	0	0	3	0	0.9
18-Jul	0	0	0	47	0	1	0	0	0.9
19-Jul	0	0	0	47	0	0	0	0	0.9
20-Jul	0	0	0	47	0	0	0	0	0.9
21-Jul	0	0	0	47	0	0	0	0	0.9
22-Jul	52	0	52	99	0	0	6	0	0.8
23-Jul	13	1	14	113	0	0	2	0	0.9
24-Jul	27	10	37	150	0	0	4	0	0.8
25-Jul	8	1	9	159	0	0	0	0	0.8
26-Jul	8	4	12	171	0	0	1	0	0.8
27-Jul	14	2	16	187	0	0	2	0	0.8
28-Jul	27	10	37	224	0	0	5	0	0.8
29-Jul	29	5	34	258	0	0	4	0	0.8
30-Jul	23	4	27	285	0	0	3	0	0.8
31-Jul	14	4	18	303	1	0	1	0	0.7
1-Aug	21	9	30	333	0	0	3	0	0.7

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Date	Sockeye adults	Sockeye jacks	Total sockeye salmon	Cumulative sockeye salmon	Pink	Chum	Coho	Coho jacks	Water depth (m)
2-Aug	37	5	42	375	0	0	1	0	0.7
3-Aug	42	11	53	428	2	0	6	0	0.7
4-Aug	79	5	84	512	0	0	8	0	0.7
5-Aug	38	6	44	556	2	12	1	0	0.7
6-Aug	156	8	164	720	6	19	2	0	0.7
7-Aug	429	0	429	1,149	15	9	0	2	0.7
8-Aug	377	9	386	1,535	52	12	14	1	0.7
9-Aug	127	10	137	1,672	2	2	7	1	0.7
10-Aug	158	2	160	1,832	15	61	7	1	0.7
11-Aug	206	14	220	2,052	3	1	1	0	0.7
12-Aug	100	7	107	2,159	2	33	2	2	0.7
13-Aug	31	2	33	2,192	0	79	2	0	0.7
14-Aug	134	12	146	2,338	12	52	9	2	0.7
15-Aug	305	15	320	2,658	657	236	29	2	0.7
16-Aug	423	3	426	3,084	1,615	119	17	0	0.7
17-Aug	218	7	225	3,309	567	124	26	2	0.8
18-Aug	252	4	256	3,565	2,218	135	74	2	0.8
19-Aug	150	3	153	3,718	1,309	93	32	3	0.8
20-Aug	58	2	60	3,778	508	49	6	1	0.8
21-Aug	136	1	137	3,915	550	69	12	6	0.9
22-Aug	51	5	56	3,971	255	12	5	6	0.9
23-Aug	225	0	225	4,196	1,873	13	0	4	0.9
24-Aug	27	0	27	4,223	107	10	0	1	0.9
25-Aug	7	0	7	4,230	41	8	96	6	0.9
26-Aug	13	1	14	4,244	17	2	62	2	0.9
27-Aug	17	0	17	4,261	199	9	10	9	0.8
28-Aug	22	6	28	4,289	125	6	4	11	0.8
29-Aug	30	6	36	4,325	185	2	6	12	0.8
30-Aug	73	0	73	4,398	1,585	80	0	17	0.9
31-Aug	132	0	132	4,530	4,761	8	0	9	0.8
1-Sep	182	1	183	4,713	7,660	4	23	4	1.3
2-Sep	40	1	41	4,754	6,823	11	40	3	1.9
3-Sep	17	0	17	4,771	7,927	7	111	3	1.7
4-Sep	28	4	32	4,803	1,381	8	14	47	1.4
5-Sep	39	3	42	4,845	297	10	22	25	1.2
6-Sep	66	8	74	4,919	221	0	4	20	1.1
7-Sep	26	1	27	4,946	160	5	2	24	1.2
8-Sep	18	0	18	4,964	171	3	193	36	1.2
9-Sep	43	3	46	5,010	314	13	5	43	1.1
10-Sep	176	9	185	5,195	943	9	27	164	1.2
11-Sep	67	1	68	5,263	2,299	8	13	100	1.5
12-Sep	26	0	26	5,289	811	6	15	70	1.4
13-Sep	26	1	27	5,316	206	5	0	64	1.4

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Appendix A.–Page 3 of 3.

Date	Sockeye adults	Sockeye jacks	Total sockeye salmon	Cumulative sockeye salmon	Pink	Chum	Coho	Coho jacks	Water depth (m)
14-Sep	13	0	13	5,329	170	6	6	68	1.8
15-Sep	25	1	26	5,355	98	2	199	66	1.5
16-Sep	50	0	50	5,405	266	1	17	193	1.3
17-Sep	38	1	39	5,444	178	2	13	131	1.2
18-Sep	43	1	44	5,488	154	5	35	142	1.3
19-Sep	57	3	60	5,548	249	0	15	122	1.2
20-Sep	22	0	22	5,570	78	2	0	135	1.3
21-Sep	42	0	42	5,612	64	0	9	243	1.5
22-Sep	17	1	18	5,630	255	3	116	110	1.5
23-Sep	20	0	20	5,650	217	1	12	80	1.3
24-Sep	211	9	220	5,870	125	2	24	265	1.4
25-Sep	19	1	20	5,890	217	4	1	96	1.7
26-Sep	8	0	8	5,898	139	1	2	106	1.4
27-Sep	9	0	9	5,907	11	0	153	156	1.4
28-Sep	14	0	14	5,921	90	0	0	214	1.2
29-Sep	93	0	93	6,014	23	1	321	141	1.1
30-Sep	21	1	22	6,036	3	0	19	107	1.0
1-Oct	22	1	23	6,059	3	0	7	108	1.0
2-Oct	6	1	7	6,066	7	0	13	75	0.9
3-Oct	10	1	11	6,077	36	0	16	201	0.9
4-Oct	5	0	5	6,082	2	0	0	224	0.9
5-Oct	0	0	0	6,082	0	0	0	0	0.9
6-Oct	85	0	85	6,167	13	0	309	205	1.0
7-Oct	5	0	5	6,172	1	0	11	92	1.0
8-Oct	6	0	6	6,178	5	0	8	80	1.0
9-Oct	7	0	7	6,185	1	0	7	18	0.9
10-Oct	37	2	39	6,224	3	0	11	41	1.0
11-Oct	0	0	0	6,224	0	0	0	0	1.0
12-Oct	0	0	0	6,224	0	0	0	0	1.0
13-Oct	13	0	13	6,237	2	0	173	116	1.0
14-Oct	0	0	0	6,237	0	0	0	0	1.0
15-Oct	22	0	22	6,259	4	0	109	88	1.0
16-Oct	0	0	0	6,259	0	0	0	0	0.9
17-Oct	0	0	0	6,259	0	0	0	0	-
18-Oct	4	0	4	6,263	0	0	0	163	-
19-Oct	0	0	0	6,263	0	0	0	0	-
20-Oct	2	0	2	6,265	0	0	144	70	-
21-Oct	2	0	2	6,267	0	0	51	133	-
22-Oct	0	0	0	6,267	0	0	0	0	-
23-Oct	7	0	7	6,274	0	0	338	127	-
24-Oct	1	0	1	6,275	1	0	259[a]	39	-
25-Oct	1	0	1	6,276	0	0	278	25	-
Totals	6,024	252	6,276	-	48,312	1,375	5,953	4,885	-

[a] Coho count on 24 October was a visual estimate by Prince of Wales Hatchery staff during high water (flooding over top of weir).

Appendix B.–Estimated percentage of sockeye escapement in each age class by return year in Klawock Lake, 1982–2003. For example, 15.2% of the sockeye spawners returning to the lake in 1982 were age-1.2 fish.

	Estimated percentage of escapement by age class									
Year	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**2.4**	**3.2**	**3.3**
1982	0	15.2	82.7	0	0.1	0.4	1	0	0.5	0
1983					no sample					
1984	28.3	23.7	29.1	0.2	3.6	9.1	5.9	0	0	0
1985					no sample					
1986	0.4	23.5	62.1	0	0.1	6.4	7.4	0	0.1	0
1987	13.4	19.4	37.2	0.1	3.9	16.2	9.4	0	0.3	0.3
1988	0	35.3	41.9	0.4	0	12.3	10	0.2	0	0
1989	3	6.9	67.3	0	0.8	10.1	11.9	0	0	0
1990	55.6	15.6	9.4	0.6	0.6	13.9	4.4	0	0	0
1991	26.4	37.2	25.7	0	4.1	5.2	1.5	0	0	0
1992	17.6	43.9	29.6	0	5.6	2.4	0.9	0	0	0
1993	6.8	20.1	50.4	0.2	4.1	8.3	9.4	0	0	0.7
1994	4.7	6.5	71	0	0.7	14.2	2.9	0	0	0
1995	26	30.7	28.9	0	2.4	4.5	7.4	0	0	0
1996	3.1	8.6	67.3	0.2	1.2	9.4	10.2	0	0	0
1997	8.5	27.2	42.7	0.2	0.6	10.2	10.7	0	0	0
1998					no sample					
1999					no sample					
2000					no sample					
2001	0.8	9.8	49.2	0.2	0.3	12.3	27.5	0	0	0
2002	0	34.7	34.3	0.5	2.8	26.8	0.9	0	0	0
2003	2.1	11.3	61.3	0	7.1	15.5	2.5	0	0	0
Mean	11.6	21.7	46.5	0.2	2.2	10.4	7.3	0.0	0.1	0.1
SE	3.2	2.5	4.2	0.0	0.5	1.3	1.4	0.0	0.0	0.0

Appendix C.–Klawock Lake temperature profiles (ºC) in 2003 by basin, depth (m), and sampling date. The shaded area represents the range of the thermocline. The thermocline is defined as the region of the lake in which the temperature drops at least 1 ºC in 1 meter.

Basin A

Depth (m)	14 May	25 June	31 July	5 Sept	23 Oct
1	10.5	13.6	17.5	15.7	10.4
2	10.5	13.6	17.3	15.4	10.4
3	10.5	13.6	17.1	15.4	10.4
4	10.4	13.6	17.1	15.2	10.4
5	10.4	13.6	16.9	15.1	10.4
6	10.4	13.6	16.7	14.9	10.4
7	10.4	13.6	16.3	14.7	10.4
8	10.3	13.6	14.4	14.5	10.4
9	10.3	13.6	15.3	14.3	10.4
10	10.1	13.6	12.2	13.9	10.4
12	8.2	13.5	10.9	13.0	10.4
14	7.2	9.0	9.4	11.0	10.3
16	6.6		-	9.3	10.3
18	6.4		-	8.3	10.3
20	6.3	7.1	7.5	7.9	10.3

Basin B

Depth (m)	14 May	25 June	31 July	5 Sept	23 Oct
1	11.0	14	18.8	15.4	10.0
2	10.8	14.0	18.8	15.4	10.0
3	10.8	14.0	18.6	15.3	10.0
4	10.8	14.0	18.4	15.3	10.0
5	10.5	14.0	18.2	15.3	10.0
6	10.1	14.0	17.7	15.1	10.0
7	8.5	13.0	14.3	15.0	10.0
8	7.3	12.0	13.3	14.8	10.0
9	7.0	11.0	12.6	14.7	10.0
10	6.7	10.0	12.2	13.4	10.0
12	6.5	9.0	10.5	11.6	9.9
13	6.4	8.0		10.6	9.9
14	6.2	8.0	9.1	9.2	9.9
16	6.1	7.0		8.4	9.8
18	6.0	7.0	7.5	7.9	9.8
20	5.7	7.0	6.9	7.3	8.9
25	5.4	6.0	5.9	6.1	7.1
30	5.3	5.0	5.6	5.8	5.9
35	5.2	5.0	5.4	5.5	5.8

Appendix D.–Dissolved oxygen profiles for Klawock Lake in 2003, by basin, depth, and sample date.

	Dissolved oxygen (mg/L)					Percent dissolved oxygen				
Depth (m)	14 May	25 June	31 July	5 Sept	23 Oct	14 May	25 June	31 July	5 Sept	23 Oct
1.0	-	10.5	8.9	9.4	10.7		-	96%	94%	95%
2.0	-	9.8	8.9	9.1	10.6		95%	96%	91%	94%
3.0	-	9.7	8.9	9	10.5		94%	96%	90%	93%
4.0	9.8	9.6	8.8	9	10.4	89%	93%	94%	90%	92%
5.0	-	9.6	8.8	8.9	10.4		93%	94%	89%	92%
6.0	9.9	9.5	8.8	8.8	10.3	88%	93%	93%	88%	91%
7.0	-	9.5	9.0	8.8	10.3		90%	88%	88%	91%
8.0	10.3	9.6	9.1	8.8	10.3	86%	89%	87%	87%	91%
9.0	-	9.7	9.1	8.7	10.3		88%	86%	86%	91%
10.0	10.2	9.7	9.2	8.6	10.3	84%	86%	86%	83%	91%
11.0	-	9.8	9.2	-	-		87%	85%	-	-
12.0	-	9.9	9.5	8.5	10.3		86%	85%	78%	91%
13.0	-	10.1	-	-	-		88%	-	-	-
14.0	10.3	10.2	-	8.7	10.3	84%	86%	-	79%	91%
15.0	-	10.3	9.8	-	-		87%	85%	-	-
16.0	-	10.3	-	9.1	10.2		87%	-	79%	90%
17.0	-	10.4	-	-	-		88%	-	-	-
18.0	-	10.5	-	9.4	10.2		87%	-	79%	90%
19.0	-	-	-	-	-		-	-	-	-
20.0	10.6	10.6	10.3	9.5	10.2	85%	87%	86%	80%	90%
25.0	10.6	10.6	10.6	8.9	9.9	85%	87%	87%	74%	86%
30.0	10.7	10.9	10.9	10.3	9.8	85%	86%	87%	83%	81%
35.0	10.6	10.9	11.0	10.4	9.7	84%	85%	88%	83%	78%
40.0	10.5	10.9	10.8	10.2	9.6	83%	85%	86%	81%	77%
45.0	10.3	-	-	9.4	-	81%	-	-	74%	-

Appendix E.–Density (number m^{-2}) of macrozooplankton by taxon in Klawock Lake, 2003.

Station A	Density (number · m^{-2}), by sampling date						Seasonal mean	Percent of total
	26-Mar	14-May	25-Jun	31-Jul	5-Sep	23-Oct		
Epischura	10	2,649	1,019	3,396	3,057	647	1,796	1.1%
Cyclops	2,267	17,524	98,998	445,322	200,713	402	127,538	78.1%
Ovig. *Cyclops*		475	170	425			178	0.1%
Bosmina	1,314	30,090	78,112	51,791	8,151	4,738	29,033	17.8%
Ovig. *Bosmina*	92	1,087		4,670	764		1,102	0.7%
Daphnia r.		136	340	14,009	2,038	188	2,785	1.7%
Ovig. *Daphnia r.*			0	849	255	10	186	0.1%
Holopedium		2,989	509	0			583	0.4%
Ovig. *Holopedium*		68	170				40	0.0%
						Total Seasonal Mean Density	163,241	

Station B	Density (number · m^{-2}), by sampling date						Seasonal mean	Percent of total
	1-Apr	14-May	25-Jun	31-Jul	5-Sep	23-Oct		
Epischura	0	4,075	16,132	6,113	8,490	4,670	6,580	2.6%
Cyclops	120,903	86,263	236,882	201,053	296,740	223,722	194,260	77.1%
Ovig. Cyclops	0	1,189	0	0	0	0	198	0.1%
Bosmina	8,151	36,169	164,714	12,905	11,462	7,217	40,103	15.9%
Ovig. Bosmina	1,189	0	0	0	0	0	198	0.1%
Daphnia r.	0	509	5,519	17,660	25,047	0	8,122	3.2%
Ovig. Daphnia r.	0	170	849	1,019	425	0	410	0.2%
Holopedium	0	849	6,368	0	0	0	1,203	0.5%
Ovig. Holopedium	0	170	4,670	340	0	0	863	0.3%
						Total Seasonal Mean Density	251,939	

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Station C	26-Mar	14-May	25-Jun	31-Jul	5-Sep	23-Oct	Seasonal mean	Percent of total
	Density (number · m^{-2}), by sampling date							
Epischura	0	2,038	8,915	4,585	11,207	2,140	4,814	5.3%
Cyclops	29,598	148,242	61,386	33,792	29,547	24,045	54,435	59.9%
Ovig. Cyclops	0	9,679	0	0	0	0	1,613	1.8%
Bosmina	3,872	35,150	62,150	9,679	7,302	12,888	21,840	24.0%
Ovig. Bosmina	458	509	0	340	0	51	226	0.2%
Daphnia r.	0	0	12,736	11,887	9,000	255	5,646	6.2%
Ovig. Daphnia r.	0	255	1,019	2,717	170	102	710	0.8%
Holopedium	0	1,528	5,094	0	0	0	1,104	1.2%
Ovig. Holopedium	0	0	3,311	0	0	0	552	0.6%
						Total Seasonal Mean Density	90,941	

Station D	1-Apr	14-May	25-Jun	31-Jul	5-Sep	23-Oct	Seasonal mean	Percent of total
	Density (number · m^{-2}), by sampling date							
Epischura	0	1,189	10,188	7,132	3,396	4,075	4,330	1.8%
Cyclops	98,149	87,451	275,514	114,281	397,776	171,336	190,751	79.2%
Ovig. Cyclops	0	3,736	425	0	0	0	693	0.3%
Bosmina	6,623	31,924	123,111	10,358	9,339	17,320	33,113	13.7%
Ovig. Bosmina	170	0	0	0	0	0	28	0.0%
Daphnia r.	0	340	13,585	20,207	18,254	0	8,731	3.6%
Ovig. Daphnia r.	0	0	3,821	2,038	425	0	1,047	0.4%
Holopedium	0	679	6,792	340	0	0	1,302	0.5%
Ovig. Holopedium	0	0	5,519	0	0	0	920	0.4%
						Total Seasonal Mean Density	240,915	

Appendix F.–Size and biomass of macrozooplankton in Klawock Lake, 2003. Mean lengths are weighted by density (numbers · m^{-2}) at each sampling date and seasonal mean biomass is based on the weighted mean length. Ovigorous (egg-bearing) individuals in each taxa were measured separately.

	Average length (mm)						Seasonal means		
Station A	**26-Mar**	**14-May**	**25-Jun**	**31-Jul**	**5-Sep**	**23-Oct**	**Mean length (mm)**	**biomass (mg/m^2)**	**% of total biomass**
Epischura	1.3	0.6	1.6	1.6	1.6	1.4	1.35	18.9	6.5%
Cyclops	0.7	0.7	0.7	0.7	0.7	0.6	0.71	223.5	76.5%
Ovig. *Cyclops*		0.9	0.9	0.9			0.88	0.5	0.2%
Bosmina	0.4	0.3	0.4	0.4	0.3	0.3	0.36	34.1	11.7%
Ovig. *Bosmina*	0.4	0.4		0.4	0.4		0.44	2.0	0.7%
Daphnia r.		0.6	0.9	0.9	0.9	1.1	0.90	10.1	3.5%
Ovig. *Daphnia r.*			1.2	1.2	1.1	1.1	1.21	1.3	0.4%
Holopedium		0.4	1.1	1.2			0.51	1.3	0.4%
Ovig. *Holopedium*		0.6	1.1				0.93	0.4	0.1%
					Total seasonal mean biomass			292	

Station B	**1-Apr**	**14-May**	**25-Jun**	**31-Jul**	**5-Sep**	**23-Oct**	**Mean length (mm)**	**biomass (mg/m^2)**	**% of total Biomass**
Epischura		0.7	1.4	1.5	1.3	1.4	1.32	64.9	12.4%
Cyclops	0.7	0.6	0.7	0.7	0.8	0.7	0.72	345.6	66.1%
Ovig. *Cyclops*		0.9					0.91	0.6	0.1%
Bosmina	0.3	0.3	0.3	0.4	0.4	0.3	0.34	43.1	8.2%
Ovig. *Bosmina*	0.4	0.5					0.42	0.3	0.1%
Daphnia r.		0.6	1.0	1.0	1.1		1.02	39.2	7.5%
Ovig. *Daphnia r.*		1.0	1.2	1.4	1.4		1.29	3.3	0.6%
Holopedium		0.5	1.1				0.99	13.4	2.6%
Ovig. *Holopedium*		0.6	1.1	1.2			1.12	12.9	2.5%
					Total seasonal mean biomass			523	

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Station C	Average length (mm) 26-Mar	14-May	25-Jun	31-Jul	5-Sep	23-Oct	Seasonal means: Mean length (mm)	biomass (mg/m^2)	% of total Biomass
Epischura		0.8	1.4	1.4	1.2	1.3	1.29	44.3	20.5%
Cyclops	0.7	0.7	0.7	0.7	0.7	0.7	0.70	92.7	42.9%
Ovig. Cyclops		0.9					0.90	4.6	2.1%
Bosmina	0.3	0.4	0.4	0.4	0.4	0.3	0.37	27.2	12.6%
Ovig. Bosmina	0.4	0.5		0.5			0.43	0.4	0.2%
Daphnia r.		0.8	0.9	0.9	1.0	1.1	0.92	21.9	10.1%
Ovig. Daphnia r.		1.1	1.3	1.3	1.2	1.1	1.26	5.4	2.5%
Holopedium		0.4	1.1				0.95	11.0	5.1%
Ovig. Holopedium		0.6	1.1				1.13	8.5	3.9%
					Total seasonal mean biomass			216	

Station D	1-Apr	14-May	25-Jun	31-Jul	5-Sep	23-Oct	Mean length (mm)	biomass (mg/m^2)	% of total biomass
Epischura		0.7	1.4	1.2	1.4	1.5	1.32	42.5	8.3%
Cyclops	0.7	0.6	0.7	0.7	0.8	0.7	0.73	346.7	68.0%
Ovig. *Cyclops*		0.9	0.8				0.90	2.0	0.4%
Bosmina	0.3	0.3	0.4	0.4	0.4	0.4	0.37	41.3	8.1%
Ovig. *Bosmina*	0.4		0.4			0.4	0.40	0.0	0.0%
Daphnia r.		0.6	0.8	1.1	1.0	1.0	0.98	38.8	7.6%
Ovig. *Daphnia r.*			1.3	1.3	1.3	1.0	1.30	8.5	1.7%
Holopedium		0.4	1.1	1.2		1.1	1.03	15.9	3.1%
Ovig. *Holopedium*			1.1				1.12	13.9	2.7%
					Total seasonal mean biomass			510	